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COMMUNICATIONS SATELLITE SYSTEMS OPERATIONS WITH THE SPACE STATION

VOLUME II - TECHNICAL REPORT

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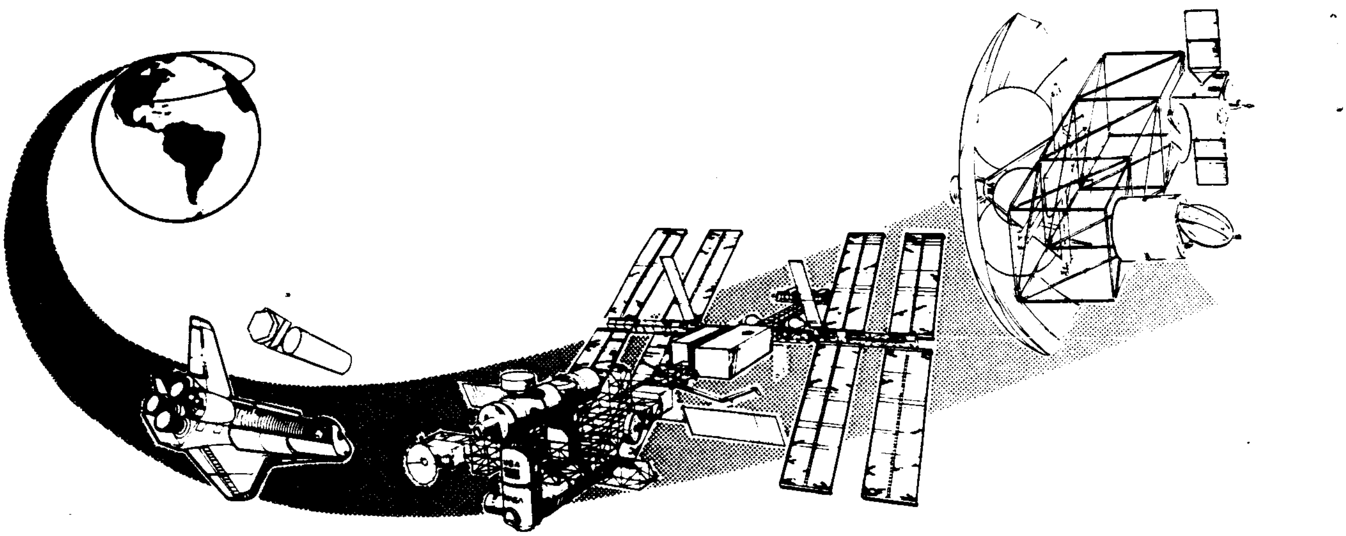

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Volume II: TECHNICAL REPORT

February 1987

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ABSTRACT

The NASA Space Station has the potential to provide significant economic benefits to commercial communications satellite operators. This report gives the results of a study to quantify the benefits of new space-based activities and to assess the impacts on the satellite design and the Space Station.

The following study results are described:

- A financial model is developed which describes quantitatively the economics of the space segment of communication satellite systems. The model describes the economic status of the system throughout the lifetime of the satellite. The economic performance is output in terms of total capital cost and rate of return on investment.

- The expected state-of-the-art status of communications satellite systems and operations beginning service in 1995 is assessed and described. The results of the assessment are utilized to postulate and describe representative satellite systems.

- New or enhanced space-based activities and associated satellite system designs that have the potential to achieve future communications satellite operations in geostationary orbit with improved economic performance are postulated and defined. These activities include retrieval, orbital transfer vehicle (OTV) launch, deployment of appendages, checkout, fueling, assembly, and servicing of satellites.

  The financial model is used to determine the economic performance of these different activities and combinations of activities. The use of the space-based OTV to transport satellites from low earth orbit to geostationary orbit offers the greatest economic benefit.

- Three scenarios using combinations of space-based activities are analyzed: (1) a spin stabilized satellite, (2) a three axis satellite, and (3) assembly at the Space Station and GEO servicing. The economic performance of the scenarios is analyzed.

- Functional and technical requirements placed on the Space Station by the scenarios are detailed. Requirements on the satellites are also listed.

The major study results are as follows:

1. Economic benefits are realizable for the commercial communications satellite industry with use of the Space Station.

2. A space-based OTV is necessary to carry out APOs in a timely and cost-effective manner.

3. A study of the economics of retrieval missions and the influence of retrieval on the insurance industry is required in order to accurately demonstrate the value of retrievability for the satellite.

4. Further NASA-sponsored study of a modular satellite design capable of being assembled in LEO (at the Space Station) and serviced in GEO is required.

5. Space Station hardware required for satellite missions should be installed as soon as possible to demonstrate NASA commitment.

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INTRODUCTION

1 Background

Commercial communications satellites form a high visibility, high benefit use of space and require a large capital investment. The NASA Space Station may have the potential to provide significant economic benefits to the commercial communications satellite operators, probably with considerable change in satellite design and operation.

The diverse objectives and lack of standardization in the commercial sector will require NASA coordination and direction to maximize Space Station benefits. NASA has taken the lead with this study which seeks to quantify the benefits of new space-based activities and assess the impacts on the satellite design and the Space Station.

2 Objectives of Study

There are three objectives of this study:

1. Develop a quantitative methodology to assess the viability of a broad range of new space-based activities, procedures, and operations (APOs) when utilized in commercial communications satellite system operations;

2. Apply the developed methodology to select which of these APOs can be competitively provided by the Space Station and its associated operating systems; and

3. Determine the economic and functional requirements imposed on the Space Station through the provision of these selected APOs.

3 Approach

The technical work is divided into the four tasks described below. Parts of Tasks 3A and 4 were done first in order to satisfy a November 1985 deadline for inputs to a Space Station requirements review.

3.1 Task 1. Develop Communications Satellite Financial Model

3.1.1 Task 1A: Develop Basic Financial Model

The objective of Task 1A is to develop a financial model that describes quantitatively the economics of the space segment of U. S. domestic Fixed Satellite Service (FSS) communication satellite systems. The model describes the economic status of the system throughout the lifetime of the satellite. The model is applicable over the range of satellites expected to be implemented over the next 10 years. Output of this task is as follows:

- A financial model which describes the economics of the space segment of FSS systems and a definition of the economic factors comprising the model.

- The values of the economic factors of three representative operating systems calculated on a year-by-year basis over the systems' lifetimes.

- The model output values of the economic performance of the three systems.

3.1.2 Task 1B: Assess Impact of System Characteristics on Financial Model Output

The objective of Task 1B is to identify those communication satellite system technical and functional characteristics that significantly affect the economic factors (used in the model developed in Task 1A) and the model output values, and to perform a sensitivity analysis.

The output of this task is as follows:

- An identification of the system characteristics affecting the economic factors in the financial model.
- The parametric relationships between the system characteristics and the economic factors.
- The results of a sensitivity analysis of the impact of system characteristics on the system economic performance.

3.2 Task 2. Determine Economic Performance of Business-as-Usual Scenario for 1995

The objectives of Task 2 are to assess and describe the expected state-of-the-art status of communications satellite systems and operations for U. S. domestic FSS systems beginning service in 1995. The results of the assessment are utilized to postulate and describe three representative satellite systems. The output of Task 2 is as follows:

- An assessment and forecast of the evolutionary improvements in spacecraft and communications technologies by 1995.
- A postulation and description of three systems incorporating the expected improvements.
- The modified values of the economic factors identified in Task 1 resulting from implementing the postulated systems. These modified values shall be on a year-by-year basis throughout the systems' lifetimes.
- The model output values of the economic performance for each of the postulated systems.

3.3 Task 3. Assess Economics of New Space-Based Activities for 1995

3.3.1 Task 3A: Postulate New Space-Based APOs

The objective of Task 3A is to postulate and define new or enhanced space-based APOs and associated satellite system designs that have the potential to achieve future communications satellite operations in geostationary orbit with improved economic performance. The availability of the Space Station and its associated systems as projected by NASA shall be assumed. Output of this task is as follows:

- Postulations and definitions of new space-based APOs to be utilized by future communications satellite systems.
- Definitions of changes in satellite system designs to accommodate the new APOs.
- By 22 November 1985 a preliminary assessment of the most significant APOs.

3.3.2 Task 3B: Evaluate Economics of APOs

The objective of Task 3B is to establish economic target values or target costs for the APOs postulated in Task 3A to provide an incentive for their implementation by the industry. The output of this task is as follows:

- Estimates of any increases in system economic performance required when the APOs defined in Task 3A are utilized during the system's life cycle.
- Economic target values for each APO defined in Task 3A.

3.4 Task 4. Develop Space Station Scenarios and Requirements

The objective of Task 4 is to describe at least two communications satellite system operating scenarios implementing different combinations of the APOs defined in Task 3 through utilization of a low earth orbit (LEO) Space Station and its supporting equipment/systems. The output of this task is as follows:

- Descriptions of two communication satellite system operating scenarios utilizing the Space Station.
- Descriptions of the functional and technical requirements imposed on the Space Station through implementation of each scenario.
- By 22 November 1985, descriptions of two communication satellite system operating scenarios utilizing the Space Station and incorporating the preliminary set of APOs, and the resulting functional and technical requirements imposed on the Space Station.

4 Organization of Report

The correspondence between the Sections of this report and the program Tasks is shown in Table I-1. Appendices A and B contain the Financial Model program output sheets for the different satellite systems.

Section	Task	Content of Section
II	1A	Financial Model Description and Validation
III	1B	Sensitivity Analysis of Model
IV	2	Technology Assessment and Definition of 1995 systems
V	2	Economic Performance of 1995 systems
VI	3A	Postulation of new space-based APOs
VII	3B	Economics of APOs
VIII	4	Space Station Scenarios
IX	4	Space Station Requirements
X	-	Recommendations
A	1A	Model Outputs for 1985 Satellite systems
B	2	Model Outputs for 1995 Satellite systems

Table I-1: Organization of Report

Section II

FINANCIAL MODEL

1 Introduction

This section describes the Task 1A development and validation of the communications satellite financial model (the Model) that describes quantitatively the economics of the space segment of U. S. domestic Fixed Satellite Service (FSS) communication satellite systems. (Ground terminals and terrestrial system costs are excluded from consideration except for satellite telemetry, tracking, and control systems.)

The Model describes the economic status of the system throughout the lifetime of the satellite beginning with its design and continuing through its construction, launch, and commercial operations. The Model can be applied to a range of satellite sizes, communications payloads, and lifetimes expected to be implemented in the 1985 to 1995 time frame.

Subsection II-2 gives the model assumptions which include both satellite technical performance and financial factors.

The three methods of financial performance measurement provided by the Model are discussed in Subsection II-3.

Subsection II-4 gives the Model *User Manual* and program description.

The Model is validated in Subsection 5 by an analysis of three representative operating systems for 1985 initial operational capability (IOC).

2 Model Assumptions

Model assumptions consist of the various input data necessary to operate the Model. They can be grouped in six categories which are discussed in turn:

1. System characteristics
2. Capital expenditures
3. Revenues
4. Operating expenditures
5. Financing activities
6. Taxes

2.1 System Characteristics

The first step in determining system economic performance is to describe the satellite system characteristics which drive both revenues and costs. To validate the Model, three 1985 systems were developed. Their characteristics are summarized in Table II-1.

These three systems are chosen because their characteristics are most representative of the current FSS environment. Although specific satellite characteristics are used, the economic factors driven by these characteristics are adjusted to reflect industry norms for the particular satellite system.

The three systems are described in the following subsections.

2.1.1 C-Band Satellite

Table II-2 lists the characteristics of the C-band satellite, which is a small spin-stabilized satellite with a payload of 24 transponders of 5.5 W power and 36 MHz bandwidth. The HS-376 design is widely used for small C-band satellites. Its relatively modest primary power requirement of 800 W makes the payload well suited to the spin stabilized design.

	C-Band	Ku-Band	Hybrid
Satellite:	Telstar 303	Satcom K2	Spacenet 1
Operator:	AT&T	RCA Americom	GTE Spacenet
Prime contractor:	Hughes	RCA Astro-Elec.	RCA Astro-Elec.
EIRP (dBW):	31-34	45-48	33-38 C, 40-44 Ku
Design life (yr):	10	10	10
BOL mass (kg):	659	1015	710
Payload mass (kg):	144	175	156
– Antenna (kg):	45	24	46
– Transponder (kg):	99	151	110
EOL power (W):	800	2440	1150
Stabilization:	Spin	Three-axis	Three-axis
Frequency:	C-band	Ku-band	C and Ku-band
Frequency re-uses			
– C-band:	2	-	2
– Ku-band:	-	2	1
Number of transponders			
– C-band:	24	-	18
– Ku-band:	-	16	6
Transponder bandwidth			
– C-band (MHz):	36	-	36 (12 each) 72 (6 each)
– Ku-band (MHz):	-	54	72 (6 each)
Transponder power			
– C-band (W):	5.5	-	8.5 (12 each) 16 (6 each)
– Ku-band (W):	-	50	16
Antenna coverages			
– C-band:	2	-	2
– Ku-band:	-	2	1
Satellite EIRP			
– C-band (dBW):	31-34	-	33-38
– Ku-band (dBW):	-	45-48	40-44
Launch vehicle(s):	Delta 3920 STS/PAM D	Ariane STS/PAM D II	Ariane, Delta STS/PAM D

Table II–1: Comparison of 1985 Satellite Characteristics

Name: Manufacturer & model: EIRP: Lifetime: On-board switching: Launch vehicle: Ground terminals:	Telstar 303 Hughes HS-376 31-34 dBW 10 yr (1985 launch) Transponders switchable from TWTA to SSPA Delta 3920 or STS/PAM D 13 m, uncooled paramp LNA, 3 kW HPA 30 m, cooled paramp LNA, 3 kW HPA
Frequency band and bandwidth: – receive: – transmit: – number of times reuse:	C-band, 500 MHz 5.925-6.425 GHz 3.7-4.2 GHz 2
Antenna – type: – number: – size: – mass: – coverage (2 beams): – polarization:	 Offset paraboloid, dual gridded 1 1.85 m 45 kg Conus or Conus and/or one spot H and V, linear
Transponders – number: – power: – bandwidth: – redundancy: – receiver redundancy: – mass: – dc power:	SSPA's and TWTA's 24 5.5 W 36 MHz 5 for 4, (18 SSPA's and 12 TWTA's, switchable) 4 for 2 99 kg 500 W
Spacecraft – type: – size (stowed): – mass, BOL: – power, EOL at summer solstice: – primary power: – batteries: – attitude and station keeping: – attitude pointing accuracy: – apogee motor:	 Spin stabilized dia = 2.17 m, length = 2.85 m 660 kg 800 W Solar cells 2 x 32 cell NiCad, 20 Ah each Hydrazine thrusters $\pm 0.05°$ Solid propellant

Table II–2: C-band Spinner Satellite Characteristics (1985)

The antenna can provide CONUS (continental United States) coverage with all 24 channels, or alternately, 6 channels can be switched to Alaska, 6 to Puerto Rico, and 6 to Hawaii.

The Telstar series is used by AT&T for video and voice. It carries both 5.5 W solid state power amplifiers (SSPA) and 5.5 W traveling wave tube amplifiers (TWTA) which can be switched between transponders by ground command in order to best suit the communications traffic being relayed by the particular transponder.

The more linear SSPAs significantly improve channel capacity. For instance, the conventional FDM/FM modulation technique allows 1,800 full-voice circuits to be carried by one transponder using a TWTA. Using companded SSB modulation, 3,900 full-voice circuits can be carried by one transponder using a SSPA of similar power.

The spinning cylinder design minimizes station keeping fuel requirements and allows space for an integral solid propellant apogee stage. However, space for solar cells is limited to the surface area of the cylinder, only one side of which faces the sun at one time. Small spinners are less expensive than three-axis satellite designs, but above a certain size the three-axis design is cheaper.

2.1.2 Ku-Band Satellite

Table II-3 lists the characteristics of the Ku-band satellite, which is three-axis stabilized with 16 transponders of 50 W power and 54 MHz bandwidth. The 2440 W power requirement due to the high power transponders favors the three axis design of the Satcom K2 satellite.

The coverage of the 16 channels can be switched on-orbit by ground command between CONUS coverage and half CONUS coverage. In addition, the 8 horizontal polarization channels can be reconfigured as a group to include Caribbean coverage.

The use of high power and east and west regional beams allows transponders to be used to distribute video services directly to 1 m receive-only terminals.

2.1.3 Hybrid Satellite

The hybrid satellite supplies transponders at two frequency bands and makes better use of an orbital position. Although there are few existing hybrid satellites, this concept will become widespread in the future.

Table II-4 lists the characteristics of the Hybrid satellite. This is a three axis satellite with 18 C-band and 6 Ku-band transponders. Twelve of the C-band transponders are 8.5 W SSPAs with 36 MHz bandwidth, while the remaining 6 transponders are 16 W TWTAs with 72 MHz bandwidth. The 6 Ku-band transponders have 16 W TWTAs with 72 MHz bandwidth.

The coverage at C-band is for CONUS, the Caribbean, Alaska, and Hawaii. Only CONUS coverage is supplied at Ku-band.

2.2 Capital Expenditures

A capital expenditure is normally an outflow of cash which is generated from debt or equity and is used to obtain an asset with a useful life usually exceeding one year. For a satellite operator, capital expenditures are comprised of the following costs:

- Satellite
- Perigee stage (if needed)
- STS launch
- Launch operations
- Mission operations
- Launch insurance

The cash outflows for capital expenditures are predetermined by milestone billing schedules negotiated between the operator and the manufacturer for the satellite and related services. NASA has established payment schedules for the STS launch.

Capital assets are depreciated over a useful life consistent with IRS regulations for financial accounting purposes. Depreciation is important because it determines the amount of taxes paid. It is assumed that five year ACRS (accelerated cost recovery system) depreciation is used

Name:	Satcom K2
Manufacturer & model:	RCA Americom, K2
EIRP:	Conus=45, half Conus=48 dBW
Lifetime:	10 yr (1985 launch)
On-board switching & processing:	Switchable among coverage regions
Launch vehicle:	Ariane IV, STS/PAM D II
Ground terminals:	As small as 1 m for receive-only
Frequency band and bandwidth:	Ku-band, 500 MHz
– receive:	14.0-14.5 GHz
– transmit:	11.7-12.2 GHz
– number of times reuse:	2
Antenna	
– type:	Offset paraboloid, dual gridded
– number:	1
– size:	1.52 m
– mass:	24 kg
– coverage (2 beams):	CONUS or E and W CONUS
– polarization:	H and V
Transponders	TWTA's
– number:	16
– power:	50 W
– bandwidth:	54 MHz
– TWTA redundancy:	11 for 8
– receiver redundancy:	4 for 2
– mass:	151 kg
– dc power:	2070 W
Spacecraft	
– type:	3-axis stabilized
– size (bus):	1.57 x 2.18 x 1.77 m
– mass, BOL:	1018 kg
– power, EOL at summer solstice:	2440 W
– primary power:	Solar cells
– batteries:	3 x 22 cell NiH, 150 Ah
– thermal control:	Heat pipes
– attitude and station keeping:	Hydrazine thrusters (electrothermal N/S)
– attitude pointing accuracy:	±0.07°
– apogee motor:	Solid propellant

Table II–3: Ku-Band Satellite Characteristics, (1985)

Name:	Spacenet 1
Manufacturer & model:	RCA
EIRP:	33-35 dBW (narrow) & 33-38 dBW (wide) C-band
	40 - 44 dBW, Ku-band
Lifetime:	10 yr (1985 launch)
On-board switching:	C- and Ku-bands interconnected
Launch vehicle:	Thor delta 3920 or Ariane
Ground terminal – C-band:	13 m, 80 K FET LNA; 18 m, 33 K uncooled paramp LNA
Ground terminal – Ku-band:	9.2 m, 11.3 m, and 13 m; 190 K FET LNA
Frequency band and bandwidth:	C-band 500 MHz, Ku-band 500 MHz
– receive:	5.925-6.425 GHz and 14.0-14.5 GHz
– transmit:	3.700-4.200 GHz and 11.7-12.2 GHz
– number of times reuse:	2 (C-band) plus 1 (Ku-band)
Antenna	
– type:	Offset paraboloid, dual-gridded
– number:	2
– size:	1.52 m
– mass:	46 kg
– coverage, 2 beams C-band:	CONUS, Caribbean, AK, and HI
– coverage, 1 beam Ku-band:	CONUS
– polarization:	H (narrow) and V (wideband) C-band, H for Ku-band
Transponders	SSPA's 8.5 W C-band; TWTA's 16 W C & Ku-bands
– number at C-band:	12 each SSPA (36 MHz), 6 each TWTA (72 MHz)
– power at C-band:	8.5 W SSPA (36 MHz), 16 W TWTA (72 MHz)
– bandwidth at C-band:	36 MHz (12 channels), 72 MHz (6 channels)
– trans. redundancy at C-band:	7 for 6, SSPA's; 8 for 6 TWTA's
– receiver redundancy, C-band:	4 for 2
– number at Ku-band:	6
– power at Ku-band:	16 W TWTA
– bandwidth at Ku-band:	72 MHz
– TWTA redundancy, Ku-band:	8 for 6
– receiver redundancy, Ku-band:	2 for 1
– mass:	110 kg
– dc power:	1,000 W
Spacecraft	
– type:	3-axis stabilized
– size (stowed):	1.32 m x 1.63 m x 1.5 m
– mass, BOL:	670 kg
– power, EOL at summer solstice:	1,150 W
– primary power:	Solar cells
– batteries:	2 x 22 cell NiH, 40 Ah each
– attitude and station keeping:	Hydrazine thrusters (electrothermal N/S)
– attitude pointing accuracy:	±0.05°
– apogee motor:	Solid propellant

Table II–4: Hybrid Satellite Characteristics (1985) to achieve the maximum tax shield in the early years of the project (Subsection 2.6.2).

For purposes of the Model, all tax benefits flow through to the parent company to be used when generated. It is assumed that the owner has other profitable operations which can use these tax benefits.

The major categories of capital expenditures are discussed in the following subsections.

2.2.1 Satellite Costs

Satellite costs are developed from the Ford Aerospace database using the Price H cost model.

The PRICE (Parametric Review of Information for Costing and Evaluation) H (Hardware) Model is a computerized method for deriving cost estimates of electronic and mechanical hardware assemblies and systems. Price H contains several thousand parametric equations that are not accessible to the user.

The fundamental inputs for Price H include the following:

- Quantities of equipment
- Schedules
- Hardware size, weight, density
- Amount of new design
- Complexity
- Maturity of technology

In order to use Price H, the first step is to create and store the hardware parametric data. Separate data files are created for the seven satellite subsystems. (Payload is divided into antenna and transponders to facilitate APO evaluation.) The database for each satellite has eight files as follows:

- Attitude control
- Power
- Propulsion
- Structure
- Thermal
- TT&C
- Payload – Antenna
- Payload – Transponder

Satellite Type	Cost $ M
C-band	38.2
Ku-band	48.2
Hybrid	43.9

Table II–5: 1985 Satellite Costs

Price H outputs another category, integration and test, which is based on the input data.

The second step involves an interaction between the user and the Price H model to calibrate the Price H output. This process typically takes one month for each new satellite database. The Ford Aerospace satellite cost database is used to validate the satellite costs.

Adding a G&A expense of 12% and manufacturer's fee of 12% to the Price H output results in the satellite costs shown in Table II-5. The satellite cost is in 1985 dollars and is an input to the Model. The cost excludes STS launch costs, perigee stage costs, launch operations, mission operations, and launch insurance.

2.2.2 Perigee Stage Costs

For 1985 systems, separate perigee stages are necessary and are assumed to be provided by the PAM D for the C-band and hybrid satellites and by the PAM-D2 for the Ku-band satellites. Prices and payment schedules for these stages are determined from McDonnell Douglas published prices.

For 1995 business-as-usual systems, some of the satellites incorporate hypothesized integrated upper stages which combine perigee, apogee, and station keeping propulsion systems. For display purposes and consistency, the cost of the perigee portion of the stage is separately displayed on the Capital Expenditure Assumption page (page 6) of the Model output.

2.2.3 STS Launch Costs

The STS launch cost is calculated based on the load factor and anticipated launch date. The launch costs in the Model are priced using current NASA rates and escalation factors. The launch cost is assumed to be contracted directly by the operator with NASA, and thereby avoids an allocation of the manufacturer's G&A expense and fee.

2.2.4 Launch and Mission Operations

Launch support and mission operations costs are derived from Ford Aerospace experience. These costs include installation of the satellite in the launch vehicle and telemetry, tracking, and control during launch and checkout and during station keeping operations.

2.2.5 Launch Insurance

Launch insurance costs are based on rates appropriate to the satellite launch date. For 1985 satellites, insurance was contracted for two or three years prior to the anticipated launch and is assumed at 14% of the insured value (1982 quoted rates for 1985 launches ranged from 12% to 15%).

Current rates range from 26% to 31% with minimal advance commitment for coverage by the insurers. These high rates reflect recent underwriter losses in excess of $600 million. Insurance rates will not decline significantly until there are numerous consecutive successful missions and the insurance industry recovers these losses.

Based on conversations with major insurance underwriters and brokers, it is assumed that in 1995 without the Space Station, insurance is priced at 20% of insured value. This price assumes that the industry has had successful launches and placements of satellites in service sufficient to allow such a drop. Otherwise, industry participants agree that current costs of 30% will prevail in 1995.

The period of coverage for launch insurance is from "intentional ignition" through checkout. The last day of the launch insurance period is when testing is completed and control is fully assumed by the operator.

Every insurance policy is unique. Each underwriter has his own methodology for computing the formula to determine the value of the sum insured. There are four basic components to consider in determining this value:

- Cost of the replacement satellite
- Cost of a replacement launch
- Loss of revenues
- Possible cost of increase in debt financing

The satellite replacement cost is the manufacturing cost plus satellite asset value (including perigee stage). The replacement launch cost consists of the charges for launch and mission operations, the actual STS launch cost, and launch insurance. Some operators also insure against the loss of contracted revenues for the period commencing at the loss or malfunction and ending when the replacement satellite has been successfully placed in orbit. However, such insurance is becoming increasingly costly.

During this time period, it is also necessary to hedge against future interest rate increases. It is possible to insure against such an occurrence in an inflationary period.

2.2.6 Payment Schedules

Payment schedules for the capital expenditures are shown in Table II-5. Payments for other than STS launch and launch insurance are largely a matter of negotiation between the operator and the manufacturer and vary widely among satellite systems.

This study assumes that 90% of the total contract value is paid during satellite construction and the remaining 10% is paid at completion of checkout with a warranty payback. Under warranty payback, the manufacturer partially guarantees satellite performance by agreeing to reimburse a portion of the 10% if there is a failure prior to the end of satellite design life.

Capital Expense	Yearly Payment, %			
	1	2	3	4
Satellite	29	40	21	10
STS Launch	18	31	51	–
Perigee Stage	29	40	21	10
Launch Support	29	40	21	10
Mission Operations	29	40	21	10
Launch Insurance	17	–	70	13

Table II–6: Payment Schedule, %/yr

2.3 Revenues

Project revenues are affected by five related factors:

1. Characteristics of transponder
2. Degradation of satellite
3. Market factors
4. Price of transponder
5. Utilization of satellite

The approach used for revenue determination is to calculate base model revenues for our representative C-band system and to index the price of other systems based on their differences from the base case.

2.3.1 Characteristics of Transponder

The following transponder characteristics impact transponder price:

- Bandwidth
- Frequency band of operation
- Power
- Transponder type

These items are discussed briefly here, with more detail presented in Section III.

The reader is cautioned against concluding that transponder prices can be reduced to a formula. General relationships are derived in order to allow the comparison of transponders with different characteristics, but it is the market that ultimately determines price.

The relationships derived below are based on market price data. As such, they may change with time if there are significant technological or regulatory changes. For instance, closer satellite spacings may lead to an interference-limited rather than the current noise-limited communications environment.

Bandwidth

Transponder price is directly related to bandwidth ratio according to the formula:

$$Price \propto k\,(Bandwidth\ ratio)$$

where $k = 0.90$. This is because the communications capacity of a channel is directly proportional to its bandwidth. The factor k is less than unity to account for the technical difficulties of passing multiple signals through a nonlinear channel.

(Note that the proper price comparison is to compare, for example, *two* 36 MHz transponders of 8 W with *one* 72 MHz transponder of 16 W.) The basis for this relationship is discussed in more detail in Subsection III-3.2.

Frequency Band

The following factors influence the relative value of Ku-band versus C-band transponders:

- Atmospheric attenuation requires a 2 to 8 dB increase in Ku-band link margin relative to C-band margins, depending on geographical location and required link availability. This translates to relative factors of from 0.8 to 0.5 for Ku-band. (This factor is partially offset by the higher allowed PFD at Ku-band – see Subsection III-2.4.3.)
- Terrestrial microwave interference may prevent use of C-band for ground transmitting in certain locations. This increases the relative value of Ku-band transponders.
- The technology at Ku-band is less mature than C-band. This decreases the relative value of Ku-band.

- C-band tends to use SSPAs versus TWTAs at Ku-band. This increases the value of C-band versus Ku-band. (See discussion below under "Transponder Type".)

It is evident that the frequency band factor is based on more than simple communications capacity, and thus there is considerable uncertainty in its actual value. Its value has been chosen to be consistent with the transponder pricing data available to us at this time. Relative transponder frequency factors are 1.00 for C-band and 0.80 for Ku-band. More detail is given in Subsection III-3.3.

The reader is cautioned against jumping to the conclusion that C-band transponders are worth more than Ku-band transponders. The greater power allowed at Ku-band (typically 50 W versus 8.5 W at C-band) and larger bandwidths used at Ku-band (typically 54 MHz versus 36 MHz at C-band) can make the price of a Ku-band transponder twice that of a C-band transponder.

Power

Transponder price varies with transponder power according to:

$$Price \propto \left(\frac{Power\ ratio}{bandwidth\ ratio}\right)^x$$

where $x = 0.33$ and the power ratio refers to transponder power divided by the baseline transponder power (same for bandwidth ratio). For example, a transponder with 5.5 W power and 36 MHz bandwidth compared to the baseline transponder with 8.5 W power and 36 MHz bandwidth has a relative price of $(5.5/8.5)^{.33} = 0.87$.

Again, this factor has been chosen to be consistent with available transponder pricing data, and may change as technology and regulations vary. More detail is given in Subsection III-3.4.

Transponder Type

The greater linearity of the SSPA versus the TWTA improves the communications capacity of a channel for the same bandwidth and power. However, the amount of increase depends on the modulation method as discussed in Subsection III-4.11, and ranges from 4% for FDM single access to 50% for SCPC modulation.

For 1985 systems the difference is small and this factor is not significant. For 1995 systems, the case will probably be that all C-band transponders use SSPAs and thus can be compared directly. Ku-band transponders will still be TWTAs and the SSPA versus TWTA factor can be folded into the frequency factor. Therefore, this factor is not explicitly included in the Model.

	Satellite System		
Year	C-band	Ku-band	Hybrid
1	1.00	1.00	1.00
2	1.00	1.00	1.00
3	1.00	1.00	1.00
4	1.00	1.00	1.00
5	1.00	.94	1.00
6	1.00	.90	.95
7	.95	.87	.90
8	.90	.85	.85
9	.85	.78	.80
10	.80	.75	.75
11	.80	.70	.70
12	.00	.00	.00

Table II–7: Satellite Degradation Curves

2.3.2 Degradation of Satellite

Degradation curves are developed which include factors for reliability, redundancy, lifetime, and the technical characteristics of the satellite. Table II-7 gives the degradation curves used for the three 1985 satellite systems described in Subsection 2.1. These curves relate to the generic satellite types, not necessarily to the specific satellite types named in Tables II-1 to II-5. The curves are for satellites with 10 year lifetimes.

These curves are composites of all factors such as infant mortality, random failures, wear-out, and the exhaustion of expendables such as propellant. The curves are based on past experience for the satellite type. For an individual satellite, variations in degradation may be expected.

2.3.3 Market Factors

Transponder lease price is determined by (1) the cost of providing the transponder; and (2) market considerations which include:

- Added features
- Competition
- Financial status of company
- Method of payment
- Orbital position of satellite
- Special package deals
- Supply and demand for transponders
- Other new or unknown factors

The market factors are not amenable to quantitative analysis but are typically the single most significant factor in determining price. It is beyond the scope of this program to analyze these factors but they are included for completeness. They determine the market price of a basic transponder, which is an input to the Model.

There is also a "market factor" input to the model in order to allow for changes in the market. The market factors are 1.00 for C-band and 1.13 for Ku-band, reflecting a preference for Ku-band transponders relative to C-band transponders.

2.3.4 Price of Transponder

The market price of a basic C-band transponder is based on a review of current in-house databases and verified through interviews with manufacturers, operators and owners, and other experts in the communications satellite field.

The three types of transponders and their respective market prices are listed in Table II-8. These prices are for 1985 C-band transponders which reflect the total market and *do not represent any particular transponder.* The prices are on a per annum basis for an average three to six year lease.

Class of Transponder	Price, 1985 ($M/yr)
Protected	1.90
Unprotected	1.40
Preemptible	.90

Table II-8: C-Band Transponder Prices

These prices represent the annualized lease cost for protected, unprotected, and preemptible transponders. The figures have been adjusted to include both inflation and an increase in operating costs over the life of the satellite, as well as customer discounts for longer leases and use of multiple transponders. Therefore, for 1985 satellites, it is not necessary to artificially inflate the base transponder prices at any point during the life of the satellite.

2.3.5 Utilization of Transponder

For this model, utilization is defined to include all transponders that have been sold or leased. The actual usage of the transponder does not matter to the Model since it doesn't influence revenues.

In today's market, owners and operators are expecting to realize 90% utilization. There is a relative abundance of C-band transponders, however, and their utilization may be considerably less. Ku-band transponders are in short supply, and their utilization may be higher.

2.4 Operating Expenditures

An operating expenditure is a cost incurred in the normal operations of the firm to sustain and support day to day activities. There are four categories of operating expenditures in this model:

- Life insurance
- Other expenditures
- Rate of inflation
- Telemetry, tracking, and control

2.4.1 Life Insurance

Life insurance is calculated as a percentage of the net present value (NPV) of the future revenue stream. Rates are based on conversations with insurance brokers, dealers and underwriters. Each policy is unique, and is not necessarily calculated using the same methodology or formula as the others.

Policies are based on the "sum insured". This value is calculated on the satellite's value less depreciation (asset value, not economic value) and lost revenue (business interruption).

The insurance premium currently ranges from 3% to 6% of the amount insured. For purposes of this model, the annual insurance premium is assumed to be 4% of the present value of future gross revenues.

2.4.2 Other Expenditures

The other operating expenses are calculated using a base amount in the launch year and an inflation premium multiplier for future years. Sales and marketing and G&A expenses are further divided into pre-operational and post-operational periods. This split permits us to employ different bases for calculations. The sales and marketing charge is calculated on a per transponder basis, but is reported on the Income Statement for the entire satellite.

2.4.3 Rate of Inflation

A 4% annual rate of inflation is forecast for the life of the project. This is consistent with the current DRI (Data Resources, Inc.) and Wharton Econometrics inflation forecasts.

2.4.4 TT&C

The telemetry, tracking, and control (TT&C) system is capable of monitoring two or three satellites. It requires a $20 million capital investment for facilities, equipment, software, etc., and an annual charge of $0.5 million for operations (salaries, maintenance, software replacement and improvement, etc.)

The TT&C cost includes both fixed (capital) and variable (operations) components; only the variable component is subject to inflation (assumed to be 4% per annum). This results in an effective inflation rate of approximately 1% of the gross amount.

2.5 Financing Assumptions

Financing decisions should be independent from investment analysis decisions. For this reason, a set of representative financing assumptions is made and held constant throughout the study.

Factors that influence financing decisions for a given project include debt ratios (debt-to-total assets or debt-to-equity), alternative methods of financing, and interest rates.

2.5.1 Balance Sheet Financing

General Balance Sheet financing is assumed. This means that the sources of funds come from internally generated equity and general company debt. A debt-to-total asset ratio of 45% is representative for a firm in the aerospace industry and is incorporated in the Model (i.e. 45% of the capital expenditures is funded with debt and the remaining 55% with equity).

2.5.2 Period of Financing

Money is borrowed as needed during the construction period. During this time, the principal accrues and only interest is paid.

Once the satellite becomes operational, level monthly payments of principal and interest are made for five years. Investment bankers agree that a five year loan is acceptable and desirable, relative to the lifetime of most satellites. If the loan period is longer, the default risk increases.

2.5.3 Interest Rates

The interest rate charged during the construction period and during operation is assumed to be variable and equivalent to the prime rate plus two points. The additional two points reflect a risk factor based on corporate creditworthiness and a charge to guarantee a line of credit. Table III-9 gives the prime rates during construction of 1985 satellites. These rates are used as a basis for calculating interest expenses in the

Year	Average Prime Rate, %
1983	14.91
1984	10.83
1985	11.91
1986	9.00

Table II–9: Prime Interest Rates

Model. (The tabulated 1986 rate is an average for the first quarter.) The prime rate is assumed to be 9% for 1995 satellites.

2.6 Tax Assumptions

All tax computations are based on the 1985 Internal Revenue Code (the Code), including all amendments and deletions. The Code and tax laws are subject to change annually as a result of Congressional legislation. Further, it is assumed that the owner/operator is a U.S. corporation or a subsidiary of a U.S. corporation and is subject to the regulations and procedures of the Code. We are evaluating this project independently and not in conjunction with other new or ongoing projects. All tax benefits are utilized at the marginal tax rates when generated. These benefits consist of investment tax credits and depreciation.

2.6.1 Investment Tax Credit

All capital expenditures qualify for an investment tax credit (ITC). The ITC is an after-tax credit which lowers the tax liability by the amount of the credit and is taken in the tax period when the satellite is placed in service.

The corporation may elect one of two ITC choices; 8% or 10%. The 10% ITC election reduces the basis for depreciation by one half of the ITC taken. The 8% ITC election gives an 8% credit after tax without reducing the depreciable base.

Based on the discount rates used in this model, an 8% ITC is chosen since the corporation realizes more benefits.

2.6.2 Depreciation

All capital expenditures also qualify for depreciation. There are three depreciation methods available (but only ACRS is implemented in the Model):

- Straight line
- Accelerated method
- Straight line/accelerated combination

In 1981, as part of the Economic Recovery Tax Act, Congress passed the Accelerated Cost Recovery System (ACRS) method for depreciation. The Act permitted accelerated recovery for most tangible property (capital purchases) placed in service after 31 December 1980. For tax purposes under ACRS, communication satellites are considered to be five year property.

The ACRS method is used because it permits the shortest depreciation period and thereby generates the greatest benefits on a present value basis.

2.6.3 Marginal Tax Rate

The project is taxed at a marginal tax rate of 49.78%. This is based on a state tax rate of 7% and a federal tax rate of 46% (any corporation with earnings greater than $100,000 must be in the 46% federal tax bracket). The aggregate rate of 49.78% reflects the deduction of state tax payments from federal taxable income.

3 Financial Analysis

The Model provides the user with three measurements of economic performance:

- Net present value of project
- Internal rate of return on equity
- Dual terminal rate of return on equity

3.1 Net Present Value

Net present value (NPV) is determined by using the sum of all current and future cash flows of the investment discounted back to time zero. The key to this method of analysis is the selection of the appropriate discount rate. In this process, careful consideration should be given to the relative risk associated with the investment. Commonly used discount rates include the investor's marginal cost of capital, alternative investment rate, and investment hurdle rate.

Advantages and disadvantages of using NPV to evaluate alternative investments are as follows (as indicated by the plus and minus sign respectively):

+ It is relatively easy to compute;
+ It effectively considers the time value of money;
+ It inherently utilizes a good reinvestment assumption;
- It gives only the current dollar magnitude of the transaction without considering the dollar value of alternative investments.

3.2 Internal Rate of Return

The internal rate of return (IRR) for an investment is that rate which, when used to discount both positive and negative cash flows back to time zero, results in a present value equal to zero. Once generated, an investment's IRR is an effective means of comparing alternative investments (regardless of the magnitude) and can also be used to evaluate individual transactions by comparing the IRR to the investor's marginal cost of capital or investment rate.

Advantages and disadvantages of using IRR to evaluate alternative investments are as follows:

+ It is widely used and understood.
+ It effectively considers the dollar magnitude of alternative investments and the time value of money.
- The IRR formula assumes all positive cash flows are reinvested at the IRR rate, which may not be realistic. For instance, if a particular project has a very high IRR, it may be unrealistic to assume that cash flow from the project can be reinvested and achieve as high a return.
- The IRR formula discounts both positive and negative cash flows using the computed IRR. Again, this may be unrealistic.
- If negative cash flows occur at various times over the life of investment, the IRR formula generates multiple solutions.

3.3 Dual Terminal Rate of Return

The dual terminal rate of return (DTRR) is similar in concept to the IRR computation. The DTRR calculation first discounts all negative cash flows back to time zero using a rate which approximates the investor's marginal cost of capital.

Next, the future value of the positive cash flows is computed assuming a reinvestment rate which approximates the one an investor could earn on other alternatives. This future value is at the end of the satellite's life.

Finally, the future value of the positive cash flows is discounted back to time zero using a rate that results in a value equal to the discounted value of the negative cash flows (i.e. NPV = 0). The discount rate used in this final step is the investment's DTRR.

Advantages and disadvantages of using DTRR to evaluate alternative investments are as follows:

+ It compensates for cash investments that are spread over several periods;
+ It allows considerable flexibility in making reinvestment assumptions;
+ It eliminates the ambiguity of multiple solutions;
+ It effectively compensates for variations in the relative size of alternative investments;
+ It accurately considers the time value of money;
- The method has increased complexity and a lack of widespread use and understanding.

It is believed that the DTRR is a superior tool for project financial analysis. While all of the financial analysis methods discussed in this section are incorporated in the Model, the DTRR is relied upon throughout this study for sensitivity analyses and choice among alternatives.

3.4 Other Financial Evaluations

The above discussion does not include a description of the Payback or Average Rate of Return techniques for investment analysis. These techniques are relatively simple to compute. However, they do not take into consideration the time value of money or the relative risk associated with alternative investments. In addition, these methods are no longer believed by most investors to provide an accurate means of evaluating alternative investments.

4 Model User Manual

4.1 Introduction

The Financial Model (the Model) is comprised of a set of *pro forma* financial statements and investment analyses tailored to the satellite industry. It is designed for use on IBM PCs, XTs, and ATs using *Lotus 1-2-3* Release 2.0 software.

The user is required to input certain financial and technical data describing the satellite being modeled. These inputs are made by responding to computer generated prompts for information via displayed menus.

The output of the model consists of an investment analysis, financial statements, and revenue, cost, financing, and tax assumptions covering the life of the project. The purpose of the output is to display the economic performance of a satellite program from the perspective of a satellite operator. Economic performance is summarized on page 1 of the output by the various measures of return on investment. The following subsections describe in detail the operation of the Model.

4.2 Accessing the Model

The Model requires an IBM PC, XT, or AT computer and *Lotus 1-2-3* Release 2.0 software. The Model is "user friendly" and displays menus that request information about the system being modeled. It is required that the user have a rudimentary understanding of the IBM PC and *Lotus 1-2-3* operations.

The first step in accessing the Model is to load the *Lotus* software into the IBM PC. Once this is done, the Model is retrieved from the floppy disk delivered as part of this study. The file name of the Model is *CSSO*. The command to retrieve the Model is given by typing "/FR CSSO" followed by a carriage return.

```
1. Input New Data
2. Recalculate Spreadsheet
3. Print Output
4. Save and Quit

Enter one of the above three choices
                 ___
```

Figure II–1: Main Menu Of Financial Model

4.2.1 Main Menu

Once the Model is retrieved from disk, the main menu is displayed on the screen as shown in Figure II-1. The user types the number corresponding to the operation desired and presses the carriage return key.

4.3 Model Inputs

The Model is comprised of several layers of assumptions incorporated into a spreadsheet model to show economic performance of satellite operations. Certain assumptions change more frequently than others and are incorporated into the menus for update by the user.

The assumptions that are not incorporated into the menus are available for update by leaving the menu and updating the spreadsheet directly. For example, satellite cost changes frequently and is a selection possible in the menu. However, the debt ratio of the operator doesn't necessarily vary with type of system and is not

GENERAL ASSUMPTIONS

	C	Ku	Other
Are there any transponders of the following types? ("1" = Yes, "0" = No)	1	0	0

Note: If there are transponders of different bandwidths, also use the Other column.

Number of Transponders	C	Ku	Other
Protected	18	0	0
Unprotected	4	0	0
Pre-emptable	2	0	0

Figure II–2: General Assumptions Menu 1

GENERAL ASSUMPTIONS

	C	Ku	Other
Bandwidth (MHz)	36	54	72
Power (W)	5.5	50	16
Degradation curve (1 = C, 2 = Ku, 3 = hybrid, 4 = user supplied)	1	2	3
Utilization (%)	90	90	90
Annual inflation (%)	4		

Figure II–3: General Assumptions Menu 2

part of the menu. The insurance rate is another parameter that is not part of the menu and must be changed directly in the spreadsheet.

The model is menu driven and prompts the user for inputs to the most frequently varied assumptions as well as for file maintenance functions such as saving and printing.

User inputs are effected by typing in numbers corresponding to menu options or system characteristics (e.g., bandwidth, power, satellite cost). The numbers are input by placing the cursor (a high-lighted cell on the PC screen) where the input is to be made, typing in the appropriate number, and pressing the "enter" key. This causes the information to be entered into the Model and also causes the next menu to be displayed.

4.3.1 General Assumptions Menu

If selection 1 is made from the main menu (Figure II-1), the first of four input menus appears on the screen. Figure II-2 is the first of two "General Assumptions" menus and requires selection of frequency band and number of operating transponders.

Up to three frequency bands may be specified for an individual satellite; C-band, Ku-band , and Other. The Other frequency assumes the revenue parameters for the C-band system. Inputting a "1" indicates that a particular frequency is present on the satellite and a "0" indicates that the frequency is not present. Transponders are input by typing the number of transponders corresponding to each frequency.

Once a particular selection is made, the next selection on the menu is made by moving the cursor using the arrow keys on the keyboard to the information requiring update and typing in the new information – either a "1" or "0" for frequency or number of transponders.

Once all the desired selections are made, the information is incorporated into the Model and the menu moves to the next set of assumptions when the return key is pressed. This method of update of satellite information is the same for all menus.

The second General Assumptions menu, shown in Figure II-3, inputs bandwidth, transponder power, degradation curve, utilization, and annual inflation rate for operating expense. Except for inflation rate, all data correspond to the frequency bands previously selected.

4.3.2 Financing and Tax Menu

The next menu to appear is the Financing and Tax Assumptions menu shown in Figure II-4. It allows the user to determine the required return on equity, capital structure, loan term, prime

Financing and Tax Assumptions	
Required return on equity (%)	18.00
% Debt in capital structure	45.00
Term of loan (months)	60
Annual average prime rate (%)	9.00
Depreciation method	ACRS
Investment tax credit (%) (0% or 8%)	8.00

Figure II–4: Financing and Tax Menu

rate, and investment tax credit election. The prime rate assumption is the basis for project interest rates, calculated at prime plus 2 points. The depreciation method is fixed at ACRS (see Subsection II-2.6.2).

Financing and tax assumptions do not necessarily change with different satellite systems. The assumptions provided in the delivered model and shown is Figure II-4 are believed to be representative of the industry. Therefore it is recommended that these assumptions remain as they are unless a change is specifically desired.

4.3.3 Capital Expenditures and Operating Assumptions Menu

The next menu to appear is the Capital Expenditure menu shown in Figure II-5. It includes the cost of the satellite, STS launch, perigee stage, launch support, and mission operations. Space is also provided for input of costs associated with OMV/OTV and Space Station support activities.

Operating assumptions are displayed on the same menu as the capital assumptions (Figure II-5). These assumptions are comprised of the number of months from the beginning of satellite construction to the beginning of satellite operation and the useful life of the satellite.

Once all of the assumptions have been updated, the user presses enter and the program returns to the main menu.

Capital Expenditure Assumptions	
Satellite cost ($M)	38.23
STS launch cost ($M)	17.19
Perigee stage cost ($M)	6.21
Launch support cost ($M)	1.64
Mission operations cost ($M)	2.55
OMV/OTV cost ($M)	0.00
Space Station support ($M)	0.00
Operating Assumptions	
Month placed in service	36
Useful life (months)	120

Figure II–5: Capital & Operating Menu

4.4 Recalculate Spreadsheet

Once the user has updated the Model for a particular satellite system, the spreadsheet is usually recalculated and then printed.

To incorporate updates of Model assumptions and to calculate revised economic performance, the user must recalculate the spreadsheet. This procedure is invoked by typing "2" on the main menu (Figure II-1) followed by "return".

The recalculation procedure requires several minutes of computer processing time, depending upon the speed of the computer. While the computer is working, the message "wait" flashes in the upper right corner of the CRT screen. When complete, the message "ready" is shown and the user may select another item from the main menu. At this point, the user would normally print out the results.

4.5 Print the Spreadsheet

4.5.1 Model Output

The output of the Model consists of nine spreadsheet pages:

1. Financial Analysis

2. Income Statement

3. Balance Sheet
4. Sources and Uses of Funds
5. Revenue and General Assumptions
6. Capital Expenditure Assumptions
7. Operating Expenditure Assumptions
8. Financing Assumptions
9. Tax Assumptions

The Financial Analysis page presents economic performance measures of dual terminal rate-of-return (DTRR), internal rate-of-return (IRR), and net present value (NPV) as well as the projects equity cash flows, required return on equity, and reinvestment rate.

The Income Statement, Balance Sheet, and Sources and Uses of Funds pages are typical financial statements.

The Capital Expenditures, Operating Expenditures, Financing, and Tax Assumptions pages display the assumptions for the particular system being modeled.

4.5.2 Print Options

Item "3" is selected from the main menu (Figure II-1) in order to print the spreadsheet. A set of printing options is displayed at the top of the main menu when option 3 is selected:

- Print all schedules
- Print support schedules
- Print statements
- Return

The user selects a particular option by placing the cursor by use of the arrow keys over the option desired and pressing the return key. The desired output then begins printing.

While the output is printing, the user cannot access the Model and the word "wait" flashes on the screen. When printing is complete, the program returns to the main menu.

If "print all schedules" is selected, all nine spreadsheets are printed in sequence. Printing is time consuming and may take several hours with a dot matrix printer or ten minutes with a laser printer. It is therefore recommended that only the spreadsheets of interest be printed.

If "print support schedules" is selected, another set of printing options appear at the top of the screen:

- Revenue
- Capital
- Operations
- Finance
- Tax
- Return

This set of print options allows the user to select any of the Model assumption spreadsheets for printing. Once a selection is made and the output printed, the user is returned to the main menu.

If "print statements" is selected, another set of print options appears at the top of the screen:

- All statements
- Analysis
- Income statement
- Balance sheet
- Sources and uses
- Return

These options allow the user to print all of the financial analysis and financial statements, worksheets or individual worksheets. Again, once a selection is made and printing is completed, the user is returned to the main menu.

If the user selects the "return" option included in all the print menus, the Model returns to the menu previously displayed.

4.6 Save and Exit Spreadsheet

The "save and quit" option on the main menu (Figure II-1) saves the updated version of the Model and exits the Model software.

4.7 Use of Model

The base model is used in Section III for sensitivity analysis. For instance, it is possible to change revenue assumptions by altering the satellite characteristics such as power or lifetime. Also, net cash outflows are affected by changes in individual capital expenditures and payment schedules. Changes in capital expenditures are also linked to financing considerations and asset size on the Balance Sheet.

Sensitivity analysis can also be performed in the operating costs category. It is possible, for example, to change the annual rate of inflation. If economic conditions either improve or worsen, new inflation factors can be incorporated into the Model.

Examples of the Model output are given next in Subsection II-5, with the actual output being given in Appendix A.

5 Model Outputs for 1985 Satellites

Appendix A contains the Model outputs for the three 1985 satellite systems. The Model outputs are validated by:

1. Calibrating each capital expenditure element; and

2. Examining current experience for expected returns for each satellite system.

By far the single greatest capital cost is satellite construction. The costs are computed through the Price H cost model and are derived from the Ford Aerospace database and validated against existing satellite systems. The basis for the satellite cost validation and the Model results are described below.

5.1 C-band Satellite

The nine pages of Table A-1 in Appendix A give the Model results for the C-band satellite described in subsection 2.1.1 and Table II-2. The DTRR return is 18.1% with a total capital expenditure of $76.5 M.

The satellite bus costs are derived from costs associated with the CS-2 contract performed at Ford Aerospace. (The C-band payload is derived from another satellite program.) Once the parameters and the cost input converge on the cost of a CS-2 satellite system, the Price H output is considered to be calibrated. By varying the parameters to those of the HS-376, the satellite costs for the Model are derived. The other capital costs are developed from current Ford Aerospace experience or published prices.

As shown in Table A-1 of Appendix A, the total capital expenditures of $76.5 M for the C-band satellite yields a DTRR return of 18.1%. Since the component requirements are validated and the return is within the expected range, the Model is considered validated.

5.2 Ku-band Satellite

The nine pages of Table A-2 in Appendix A give the Model results for the Ku-band satellite described in subsection 2.1.2 and Table II-3. The DTRR return is 19.8% with a total capital expenditure of $104.3 M. The better return than the C-band satellite is due to the higher revenues from the high power Ku-band transponders.

The Ku-band satellite costs are based on costs derived from two Ford Aerospace programs; Intelsat 5 and Ford Satellite. The costs are validated in a manner similar to the C-band satellite described above to yield an expected cost for a RCA K2-type satellite system.

5.3 Hybrid Satellite

The nine pages of Table A-3 in Appendix A give the Model results for the hybrid satellite described in subsection 2.1.3 and Table II-4. The DTRR return is 21.9% with a total capital expenditure of $83.1 M. This satellite achieves the best return due to the combination of high revenues from a mix of C and Ku-band transponders at a relatively modest increase in costs.

The hybrid satellite costs, like those of the Ku-band satellite, are based on costs derived from the Intelsat 5 and Ford Satellite programs. The costs are validated as described above to yield an expected cost associated with a GTE Spacenet type satellite.

5.4 Discussion

These results achieved are in agreement with the current experience of satellite system owners and operators. Because of this and the validation process involved in calibrating each capital expenditure element, the Model is considered to be validated. Section III will further validate the Model by investigating its sensitivity to variation of system parameters, and verifying that the results correspond to the current experience of the industry.

Section III

IMPACT OF SYSTEM CHARACTERISTICS ON ECONOMICS

1 Introduction

This section describes the selection of system characteristics and the Task 1B sensitivity analysis of the impact of the system characteristics on system economic performance.

Subsection 2 gives the basis for the choice of communication satellite system technical and functional characteristics that significantly affect the economic factors and output values of the financial model (the Model). These system characteristics are divided into three groups; primary, secondary, and financial, which are discussed in Subsections 3, 4, and 5.

2 Choice of Characteristics

The fundamental purpose of a communications satellite is to provide communications capacity. Shannon's equation (Equation 1) gives the maximum communications capacity of a channel. The satellite link equation, solved for the uplink and downlink cases, gives the technical factors that influence the carrier-to-noise ratio (C/N_0). Regulatory constraints in order to limit interference are a third factor that impacts system performance.

2.1 Channel Capacity

The value of a communications link depends on its capacity, which is defined as the maximum rate at which information can be transmitted without error. Without telling how to achieve it, Shannon's equation gives an upper bound on channel capacity:

$$H = B \log_2 \left(1 + \frac{C}{N}\right) \tag{1}$$

where

H is the link capacity

B is the link bandwidth

C is the carrier signal power

N is the noise power

Bandwidth is chosen as a primary characteristic since communications capacity varies directly with it.

C/N has a logarithmic influence on capacity; changes cause greater effects for small values of C/N than for large values. In practice, the multiple access technique and modulation scheme determines the required minimum value for C/N, and the system is engineered to exceed this value.

2.2 Satellite Link Equation

The factors that influence C/N can be seen by consideration of the satellite link equation. The fundamental equation for RF link performance is as follows:

$$\frac{C}{N_0} = \frac{EIRP}{k\,L_s}\left(\frac{G_r}{T_s}\right) \tag{2}$$

where

C is carrier signal power

N_0 is the noise power per unit bandwidth

$EIRP$ (effective isotropic radiated power) is the transmit gain times power

k is Boltzman's constant

L_s is the free space path loss

G_r is the receive antenna gain

T_s is receiver system noise temperature

The relationship for path loss is as follows:

$$L_s = \frac{(4\pi R)^2}{\lambda^2} \tag{3}$$

where R is distance and λ is wavelength.

The relationship between the receive antenna gain, G_r, and effective area, A_r, is as follows:

$$G_r = \frac{4\pi \eta A_r}{\lambda^2} \tag{4}$$

where η is antenna efficiency.

The satellite communications link is made up of both downlink and uplink segments which are analyzed in turn.

2.2.1 Downlink Communications

An important constraint for FSS satellite communications is that the satellite transmit antenna gain is fixed by the required earth coverage area. Using Equations (3) and (4), Equation (2) can be rewritten as follows:

$$\frac{C}{N_0} = \frac{K_1}{4\pi k S}\left(\frac{\eta A_r}{T_s}\right) P_t \tag{5}$$

where

K_1 is a constant equal to the transmit antenna gain times its solid angle

k is Boltzman's constant

S is the coverage area

η is the receive antenna efficiency

A_r is the receive (ground) antenna area

T_s is receiver system noise temperature

P_t is the transmit power of the satellite

Link performance depends on the receive antenna efficiency and area, the transmit power, and the receiver system noise temperature, but *not* on operating frequency. (However, frequency is important for the other reasons of device performance, atmospheric losses, and interference with other systems.) It is the physical size of the ground receive antenna that is important, not its gain.

2.2.2 Uplink Communications

For the uplink segment, if the satellite receive antenna coverage on the earth is specified, Equation (2) becomes:

$$\frac{C}{N_0} = \frac{K_1}{4\pi k S}\left(\frac{\eta A_t}{T_s}\right) P_t \tag{6}$$

where

A_t is transmit (ground) antenna area

T_s is receive system temperature of sat.

P_t is transmit power of the earth station

Thus, for both uplink and downlink, performance depends on the ground antenna physical size and *not* on the transmit and receive antenna gains.

The satellite transmitter power, rather than EIRP, is the important factor since satellite antenna gain is a constant for systems with fixed coverage areas. Power can be compared across frequency bands, provided atmospheric attenuation is taken into consideration.

2.2.3 Technical Characteristics

The factors influencing C/N_0 can be seen from Equations (5) and (6). Satellite transmit power is a primary characteristic.

The ground terminal requirements including antenna size, antenna efficiency, system noise temperature, and ground transmit power are secondary characteristics due to the limited relative value of the ground segment for 1985 systems. The satellite receiver system noise temperature is a secondary characteristic due to its limited range of variation. The coverage area is a secondary characteristic due to constraints on its variation.

CITY	Rain Zone	Margin (dB)
Eastport, Maine	B	3.7
Miami, FL	E	10.0
New York City	D	6.3
San Diego, CA	F	2.0
Seattle, WA	C	3.3

Table III–1: Ku-Band Weather Margins

2.3 Atmospheric Attenuation

The atmosphere attenuates the transmitted signal and decreases C/N. The amount of attenuation depends on transmission frequency and path length through the atmosphere (i.e. elevation angle of satellite as viewed from the ground and altitude above sea level). There is both a fixed component of the attenuation due to molecular oxygen and a variable component due to water in its various forms.

Rain, snow, and ice in the atmosphere also depolarize the signal, resulting in interference between the orthogonally polarized signals commonly used for frequency reuse.

At C-band, the normal atmosphere has negligible attenuation and heavy rain can cause up to 2 dB loss. At Ku-band, the normal atmosphere has 0.5 dB loss and heavy rain can cause up to 10 dB loss.

Table III-1 gives the link margins recommended for 99.9% Ku-band signal availability by RCA Americom for commercial satellite operators in different cities.

For 100% reliability, operations in areas of frequent heavy rainfall, or operations at elevation angles below 10°, C-band has a considerable advantage over Ku-band.

2.4 Regulatory Considerations

The purpose of international and national regulations on telecommunications is to limit interference among different communications links.

2.4.1 Interference

Interference from unwanted signals acts like system noise to degrade performance. The maximum allowable carrier-to-interference ratio C/I depends on the tolerance of the communications system to interference. For instance, FM modulation, used for TV transmissions, exhibits a strong "capture" effect whereby the receiver locks onto the strongest available signal and is relatively tolerant to unwanted signals.

As long as C/I is greater than C/N, the system is noise limited. Such a design is desirable in that it permits individual users to improve their quality of service by using lower noise figure receivers. (Users could improve their performance even more by purchasing larger receive antennas.)

Interference can arise from either misdirected energy (in antenna sidelobes) or from the out-of-band energy of one channel falling in the band of another channel. An extensive body of regulations exist in order to keep interference at tolerable levels.

2.4.2 Ground Antenna Sidelobes

In order to allow 2° satellite spacing, the FCC specified in the *1983 Orbital Assignment Order* the maximum sidelobe levels for ground transmit antennas. Table III-2 gives the maximum allowable antenna gain in dBi as a function of off-axis angle θ in degrees in the plane of the geostationary orbit and elsewhere (orthogonal to the plane). (Limits are also placed on cross polarization isolation by the FCC.)

Minimum transmit antenna sizes of around 80 wavelengths (4 m at C and 2 m at Ku-band) are required to meet these FCC specifications. For ground receive-only applications, it is the responsibility of the user to provide sufficient protection from interfering signals.

2.4.3 Power Flux Density Limits

WARC regulations place limits on the maximum ground power flux densities (PFD) in any 4 kHz bandwidth to -142 dBW/m^2 at C-band and -138 dBW/m^2 at Ku-band for angles of arrival

GEO ORBIT PLANE		
Maximum Allowable Gain (dBi)	Off-Axis Angle (degrees)	
	From	To
29 - 25 log θ	1.0	7.0
+8	7.0	9.2
32 - 25 log θ	9.2	48.0
-10	48.0	180.0
ELSEWHERE		
32 - 25 log θ	1.0	48.0
-10	48.0	180.0

Table III–2: Ground Antenna Standards

greater than 25° above the horizon. Equivalent EIRPs over a 36 MHz bandwidth are 60 and 64 dBW respectively.

However, satellites providing CONUS (continental United States) coverage from an extreme orbital position such as 65° W or 130° W are 10° or less above the horizon at the opposite northern CONUS corner. The PFD limit drops up to 10 dB for low elevation angles. (The additional path loss and atmospheric attenuation loss at 10° are 2 dB and the EIRP limits only drop 8 dB.)

The effective operational limits are even lower. The 1979 *ITU Radio Regulations* for Region 2 limit Ku-band EIRPs to approximately 50 dBW maximum for FSS. (The DBS band is set aside for higher power, direct transmissions of TV to customers.)

The important consideration is to limit interference among satellites. Higher power in one satellite translates to higher interference in its neighbors. The regulatory trend is to keep all satellites to the same radiated power per unit bandwidth.

C-Band

The emphasis is on low cost and low risk for medium to high density traffic. Operational limits on transponder power for 1985 satellites. are 8.5 W for CONUS coverage and 36 MHz bandwidth, and may increase slightly to 10 W for 1995 satellites. This corresponds to 36 dBW EIRP.

There are no motivating factors to go to high power as the present day 34 dBW EIRP gives 99.98% availability and allows 3 m TVRO reception. Furthermore, the 2° satellite spacing places lower limits on ground antenna sizes.

Ku-Band

In order to achieve the same performance as C-band with the same ground antenna size, more power is required for the Ku-band signal to compensate for atmospheric attenuation (Subsection 2.3).

Transponder power is limited to 50 W for 1985 and an estimated 100 W for 1995 satellites, for CONUS coverage and 54 MHz bandwidth. These correspond to 45 dBW and 48 dBW EIRPs. Interference considerations drive these limits. A satellite power of 50 W allows use of 2 m earth terminals for two-way, low data rate customer premise services. There are diminishing returns with higher satellite power in that more ground transmit power is required to offset the smaller ground antenna.

3 Primary Characteristics

The following primary factors that most directly affect the satellite economics have been identified:

1. Communications capacity of satellite
2. Bandwidth of channel
3. Frequency band of operation
4. Power of channel
5. Utilization of satellite

Satellite costs are typically around one third of the revenues. Thus, those characteristics that influence revenues are more significant than those that influence cost and have greater effects on the rate-of-return to the operator.

Market factors, discussed in Subsection III-2.3.3, have a great impact on transponder price and hence economic performance. It is beyond the scope of this study to discuss and analyze their impact. However, the results for variation in utilization as given in Table III-6 are the same as for market factor variation. (For instance, a 25% drop in transponder price is equivalent to a 25% drop in utilization.)

The market factor may change with time. For instance, the present conditions of a plentiful supply of C-band transponders and a shortage of high power Ku-band transponders is not likely to last through 1995.

3.1 Communications Capacity

Communications capacity is determined by the total bandwidth used by the satellite, including possible frequency reuse via two polarizations and multiple spacially separate beams.

The World Administrative Radio Conference (WARC) 1985 *Allotment Plan* would expand the presently available 500 MHz of bandwidth by 300 MHz to 800 MHz at C-band and by 500 MHz to 1 GHz at Ku-band. Since this is still in the planning stage, for purposes of this program the present 500 MHz allotments are used.

A satellite design is optimized in terms of size and power for its communications capacity. To reduce capacity for a particular design does not make economic sense. To increase capacity requires increased mass, power, and launch capability, typically meaning a new satellite design.

Thus, analysis of communications capacity must compare different satellite designs. Table III-3 compares the economic performance of the three 1985 satellites. The revenues are for equivalent 36 MHz transponders. The different revenue figures also reflect other features of the satellites such as different transmit powers and operating frequencies. The dual terminal rate of return (DTRR) is the bottom line financial result, reflecting satellite manufacturing, launch, and operating costs.

The conclusion is that due to economies of scale, satellites with greater communications capacity yield better rates of return on the capital invested. However, there are limitations on the maximum capacity of one satellite due to launch vehicle constraints, insurance limitations per single launch, and market for transponders.

Satellite Type	Capacity MHz	Revenue \$M per transponder	Return (DTRR) %
Telstar	864	1.6	18.1
K2	864	2.0	19.9
Spacenet	1,296	1.2	21.9

Table III-3: Capacity Versus Cost

3.2 Bandwidth of Channel

The bandwidth of the communications channel is directly related to the communications capacity of the channel as per Equation (1). Thus, it is expected that transponder price is directly proportional to bandwidth:

$$Price \propto k\,(Bandwidth)$$

where $k = 1$. However pricing data suggests a lower value, $k = 0.9$, which we use in the Model. One reason for this is the technical difficulty of passing a greater number of signals through a single transponder that is nonlinear.

Bandwidths smaller than 36 MHz are unlikely to be available for FSS service by 1995 due to the increased manufacturing costs and limited demand.

The total available communications bandwidth is the limited resource. The choice is one of number of channels, i.e. 16 @ 54 MHz or 24 @ 36 MHz, and the total satellite revenue tends to remain the same. Note that the total power of all transponders also remains the same in order to keep the power radiated per unit bandwidth the same. However, satellite cost and mass increases as channel bandwidth is reduced on account of the increased number of components.

3.2.1 C-Band Channel Bandwidth

C-band FSS supplies low cost, low risk communications for medium to high density traffic. The 500 MHz available band is packaged in 36 MHz bandwidth units for the historical reason that it allows FM transmission of a single TV channel. The 36 MHz bandwidth can also transmit 1,000 FDM/FM or 1,600 SCPC voice channels.

Use of this standard transponder bandwidth will continue, with some larger channels available for wider band transmissions.

3.2.2 Ku-Band Channel Bandwidth

Both 54 MHz and 72 MHz bandwidths are in use at Ku-band. Bandwidths wider than 36 MHz were used because of satellite mass and power limitations. Some satellite designs could not carry enough payload for 24 transponders (36 MHz each), but 16 transponders (54 MHz each) were possible.

With 1995 technology, this limitation is removed and smaller bandwidths such as 36 MHz will be used for FSS service. This facilitates interconnection between C and Ku-bands. Bandwidths smaller than 36 MHz are unlikely to be offered because of the inefficient use of bandwidth due to increased guard bands. The nonlinear characteristics of the TWTAs required for high power operation makes the use of very wide bandwidths inefficient.

3.3 Frequency Band of Operation

The need for greater communications capacity than that offered by the 500 MHz at C-band led to the utilization of the 500 MHz bandwidth at Ku-band and leads to use of the 2,500 MHz bandwidth at Ka-band.

The relative advantages and disadvantages of Ku-band compared to C-band are as follows:

+ Ku-band has higher allowable transmit power.

+ C-band transmissions are regulated to avoid interference with existing ground microwave facilities. Ku-band does not have this problem.

+ C-band typically uses SSPAs which are more linear than the TWTAs used at Ku-band, and can result in greater channel capacity (see Subsection 4.11).

– Ku-band has less mature technology than C-band with the consequent greater costs and risks.

– Ku-band requires from 2 dB to 8 dB more weather margin than C-band links (Subsection 2.3).

Note that the the link equations given by Equations (5) and (6) contain ground antenna size and not gain. Thus, for a given desired system performance, ground antennas at Ku-band must be *larger* than those at C-band on account of rain attenuation. The reason Ku-band ground antennas are generally smaller is that more power may be transmitted by the satellite.

The relative value of Ku-band and C-band transponders of similar power and bandwidth can be estimated by taking 2 dB from the Ku-band transponder power to account for added weather effects. The 2 dB power assessment against Ku-band is equivalent to a 0.9 relative price for Ku-band versus 1.00 for C-band (see Subsection 3.4). (If 100% availability is required, there is an 8 dB difference, and a 0.65 cost factor.)

The conclusion is that these points counterbalance each other and the frequency band factor is 0.80 for Ku-band versus the baseline 1.00 for C-band for 1985 and 1995 satellites. The frequency factor may change with time, particularly if FCC regulations change.

3.4 Power Transmitted in Channel

In the past, satellite mass and primary power constraints have limited available transmit power. New, larger satellites overcome these constraints and now the scarce resource is available communications bandwidth. Power is primarily limited by considerations of interference among satellites and efficient use of bandwidth.

Another important factor is to make efficient use of bandwidth. Higher power transponders, depending on modulation method, may "waste" bandwidth by requiring use of more dispersal or spreading waveforms for the carrier. (It has been estimated that 3 MHz of bandwidth is wasted by use of a 25 W C-band transponder for CONUS coverage.)

Table III-4 gives typical values for "protected" transponder price as a function of power. Data is presented separately for the two bands, refer-

Relative Power (dB)	Transponder Price ($/month)	
	C-band	Ku-band
0	150,000	300,000
-3	122,000	244,000
-6	-	198,000

Table III–4: Transponder Price versus Power

enced to different baselines. The 0 dB or baseline power are 8.5 W for a 36 MHz C-band SSPA transponder and 50 W for a 54 MHz Ku-band TWTA transponder. The data was obtained by comparing a number of satellites.

Transponder price varies according to the transmit power per unit bandwidth:

$$Price \propto \left(\frac{Power}{Bandwidth}\right)^x$$

where $x = 0.33$. Future Ku-band services are planned using high power satellites and small ground terminals. For these systems, the ground segment may consist of 100,000 terminals and represent a larger investment than the satellites. In this case, transponder price could depend more strongly on power, perhaps $x = 1$.

3.4.1 Impact on Satellite

Table III-5 summarizes the impact on satellite mass of a 3 dB reduction in transponder power for the Satcom K2 satellite. The 16% reduction in BOL mass was reflected by an equal percentage reduction in satellite cost as determined by the Price H cost model. This is consistent with the transponder price data.

3.4.2 EIRP

As pointed out in Paragraph III-2.2.2, satellite power rather than EIRP is the important factor for links with fixed coverage area since antenna gain is a constant. This is the case as utilized by the Model; fixed CONUS coverage is considered.

If the satellite system utilizes frequency reuse via spatially separate beams, the beam EIRP rather than power must be used to determine

Satellite Subsystem	K2 Mass (kg)	
	50 W	25 W
Power	233	166
ADCS	39	39
TT&C	27	27
Propulsion	100	96
Structure/thermal	159	145
Comm. payload	175	175
Harness	40	40
RCS (10 yr)	242	164
TOTAL (BOL mass)	1,015	852
Deployed Mass (STS)	5,538	4,775

Table III–5: Effect of Power Reduction on Mass

transponder price. This can be done by adjusting the transponder power input to the Model such that it is in the same ratio to the baseline satellite power as is the EIRP. The baseline 8.5 W C-band satellite with CONUS coverage has 36 dBW EIRP. The baseline 50 W Ku-band satellite with CONUS coverage has 45 dBW EIRP.

For satellites with regional beams, the actual power must be adjusted according to the coverage area. For example, 50 W into a half CONUS beam would be input into the Model as 100 W.

3.5 Utilization

Utilization is the percentage of the satellite's communications capacity that is sold or leased, and thus has a direct effect on economic performance. Table III-6 gives the rate of return for a K2 type satellite for different utilization rates. In order to achieve the targeted 18% rate, 85% utilization is required.

Both dual terminal (DTRR) and internal rate of return (IRR) are plotted. The DTRR invests profits at the target 18% rate, while the IRR assumes investment of profits at the same rate being realized from the satellite.

Satellite Utilization (%)	Total Revenue ($M/yr)	Rate of Return	
		IRR (%)	DTRR (%)
40	21.3	0.5	9.7
50	26.6	5.4	12.2
60	31.9	9.5	14.2
70	37.2	13.2	15.9
75	39.9	14.9	16.7
80	42.5	16.5	17.4
85	45.2	18.0	18.0
90	47.8	19.7	18.6
95	50.5	21.0	19.2
100	53.2	22.4	19.8

Table III–6: Utilization Versus Rate-of-Return

4 Secondary Characteristics

The following set of secondary factors are discussed below:

1. Attitude control and pointing accuracy
2. Coverage area
3. Ground terminal requirements
4. Lifetime of satellite
5. Mass and volume of satellite
6. Maturity of technology
7. Noise temperature of satellite receiver
8. On-board switching
9. Primary power of satellite
10. Reliability of satellite
11. Time delay in launch
12. Transponder Type

The majority of these secondary characteristics are interrelated with each other and the primary characteristics, and thus are not amenable to quantitative analysis.

4.1 Attitude Control and Pointing

The accuracy of satellite attitude control and antenna pointing depends on the size of the individual antenna beams or service coverage areas. Edge-of-coverage gain and isolation between different beams are affected by pointing inaccuracy.

In general, pointing accuracy requirements increase with frequency of operation due to the feasibility of obtaining smaller beam sizes from the same size antenna. More spatial frequency reuse also increases pointing accuracy requirements due to the smaller coverage areas of the individual beams. Accuracies of $\pm 0.1°$ are adequate for C-band and $\pm 0.05°$ for Ku-band.

Higher pointing accuracy requires more frequent satellite station-keeping adjustments. Alternately, active steering of the antenna could be used. In either method, greater satellite costs are incurred. Since the attitude control and pointing requirements follow directly from the choice of payload, this item is not of primary importance.

4.2 Coverage Area

Service coverage areas are determined by the location of traffic and the number of frequency reuses. A single reuse covers CONUS with one horizontal and one vertical polarization beam. Further reuse divides CONUS into a number of alternating H and V beams. The coverage area shapes must be matched to the communications traffic.

The key tradeoff is the desired communications capacity. Greater capacity requires more coverage areas which generates more revenue but cost more to provide.

4.3 Ground Terminal Requirements

The scope of the present work excludes ground terminals and terrestrial systems, except for TT&C facilities, from consideration in the financial model. Thus, economic analysis is not done for the ground terminal, but a brief discussion is included for completeness.

As seen from the link equations, satellite transmit power is inversely related to ground antenna area and performance. The impact of the ground terminal on economic performance depends on the relative costs of the space and ground segments of the system.

The following characteristics of the ground terminal are important:

- Antenna efficiency
- Antenna effective area
- System noise temperature
- Transmit power

Improvement in C/N can be obtained by improving satellite performance or ground terminal performance. Less expensive (i.e. smaller) ground terminals are indicated for systems with large ground segments.

4.3.1 C-Band Ground Terminals

The C-band ground terminal is typically a Class B 10 m antenna. The present large number of C-band antennas for TVRO (TV receive only) will move to Ku-band in the future. The use of C-band will be for high priority voice communications where weather outages are not tolerable. Therefore, C-band will continue to use relatively large and expensive ground stations and will not have low cost ground terminals as a cost driver.

4.3.2 Ku-Band Ground Terminals

Ku-band typically uses 6 m antennas for business services – two-way video conferencing or multiple voice circuits. The benefit of a higher power satellite transponder in reducing ground antenna size is offset by the uplink requirement for increased ground transmit power. A further minimum on antenna size is determined by the 2° satellite spacing.

TVRO business is coming to this band, and the issue of small low-cost ground terminals is very important in terms of being a cost driver. (TVRO is not as sensitive to outages as voice, and thus Ku-band with its weather outages is more appropriate for TVRO.) There will continue to be large 10 m ground terminals used for high density trunking.

Satellite Lifetime (yr)	Satellite Mass (kg)	
	Spacenet	Satcom K2
7	670	974
10	710	1,018
12	750	1,083

Table III–7: Satellite Lifetime Versus Mass

The analog modulation schemes in use at C-band do not allow a user to take advantage of a larger or smaller ground antenna. A certain size antenna is required to achieve the required C/N, and increased size achieves only a small improvement in quality. Digital modulation schemes, likely to be employed at Ku-band, will allow variation in communications capacity with C/N. A mix of different size ground terminals could use the same satellite, each using the appropriate capacity.

4.4 Lifetime

Satellite lifetime is determined by the lifetimes of its critical components and the amount of station-keeping fuel that is carried. Components with short lifetimes can be utilized if there is enough on-board redundancy to replace failures occuring during the design life of the satellite.

Current satellite designs are optimized regarding payload, mass, and lifetime. Thus, the inclusion of more mass for redundant components in order to extend life requires a mass reduction elsewhere.

The use of a larger upper stage to launch the heavier satellite is not economically feasible. Typically the satellite is designed at the mass limit for the upper stage, and a larger upper stage does not exist or is grossly oversized.

Table III-7 shows the variation in satellite BOL (beginning of life) mass with lifetime for the 1985 satellites Spacenet and K2. Mass changes by ±5% as lifetime is varied from 10 years to 7 or 12 years. The impact on satellite cost is approximately the same.

The conclusion is that lifetime is determined

Lifetime (yr)	Rate-of-Return, %	
	DTRR	IRR
9	22.0	27.8
10	21.9	28.1
11	21.8	28.2

Table III–8: Rate-of-Return Versus Lifetime

from an overall design tradeoff of component lifetimes, satellite mass, and launch costs. For 1985 satellites this optimum is 10 years. Longer lifetime satellites are not feasible due to launch vehicle constraints an the unfavorable economics of including and paying for redundant equipment that does not generate revenue for 10 years. Short lifetime satellites are not economically feasible since there is little reduction in cost but a large reduction in revenue. A further problem with longer lifetimes is technical obsolescence.

A quantitative analysis of a 12 year lifetime 1995 hybrid satellite was done and compared with the baseline 10 year satellite. The 1995 satellite design was used on account of the requirement to use the OTV for upper stage launch of the heavier (+65 kg) 12 year design.

The satellite cost increased $4.3 M, changing capital cost from $138.8 M to $144.3 M. The DTRR return decreased .5% from 21.9% to 21.4% for the longer life satellite. The reason for the poorer performance, in spite of two additional years of revenue, lies in the requirement for redundant components to be purchased and incorporated into the satellite, but not used for 10 years.

A further sensitivity study was done by keeping capital costs the same but changing lifetime from 9 to 10 and to 11 years. For the 1995 hybrid satellite, Table III-8 shows how the DTRR and IRR rates-of-return change. The IRR improves only slightly with longer lifetime due to the discounted value of revenues far in the future. The DTRR actually decreases slightly. As shown in Subsection III-4.11, a time delay at launch has much more effect than a similar time loss at the end of life.

4.5 Mass and Volume

The satellite communications capacity determines the satellite mass and volume. Thus, increased capacity gives increased mass which in turn leads to increased revenues and increased costs. Larger satellites tend to have lower costs per unit communications capacity.

Limitations on mass and size, and thus payload, are placed by the launch vehicle mass capacity and size envelope. Limitations may also be placed by insurance capacity for a single payload and transponder market capacity.

4.6 Maturity of Technology

New technology initially has lower reliability, and is incorporated into the satellite design only after careful testing. This process results from the inherent conservatism of the commercial satellite users and their bankers and insurance brokers. Higher frequency band technology is typically less mature than that at lower frequency bands, and costs more to use.

4.7 Noise Temperature of Receiver

The total system noise temperature is the sum of many components:

- Receiver noise figure
- Feed and beamforming network losses
- Radiation from ground or spacecraft
- Radiation from atmosphere

As seen from Equation (5), a decrease in receiver system noise temperature directly improves C/N_0. Consistent with reliability, the satellite receiver utilizes the best available LNA (low noise amplifier) in the receiver. Cooled receivers are as yet too heavy and unreliable for space use. Other contributions to system noise temperature such as antenna pattern and feed noise are also minimized. The conclusion is that although important, the satellite receiver system noise temperature is optimized and will not be varied.

For the ground station on the downlink performance, there will be variation depending on its

Type of Transponder Interconnection	Relative Price (%)
Interconnected pair	101
Hybrid pairs	
C receive, Ku transmit	140
Ku receive, C transmit	120

Table III–9: Price of Interconnectivity

size and cost. Smaller, low cost ground stations have less expensive receivers. Large ground stations may have cooled receivers. However, the contribution from the warm ground and the atmosphere keeps a lower limit on practical system noise temperatures.

4.8 On-board Switching

Technology is allowing the feasibility of other than satellites with "bent pipe" transponders, but marketing is needed to establish demand. On-board interconnectivity between different beams at the same frequency or different channels at different frequency bands appears to be attractive to users. Note that bandwidth must be the same at C and Ku-bands in order to allow interconnection.

Table III-9 gives an estimate of the relative transponder price for the different types for interconnectivity. The price refers to the percentage of the standard C and Ku-band transponder price.

On-board processing such as planned with NASA's ACTS satellite is judged to be too expensive for commercial application in the 1985 to 1995 time-frame.

4.9 Primary Power

Satellite primary power requirements are mainly determined by the payload, in particular the number and power of the transponders. However, for a given coverage area and frequency band, there is a regulatory limitation on total transmit power regardless of the number of spatial frequency reuses. This is because more reuse divides CONUS into smaller regions, each requiring less power.

Frequency Band	Transponder Type	Power (W) 1985	Power (W) 1995
C	TWTA	500	410
C	SSPA	1,200	660
Ku	TWTA	3,600	2,500

Table III–10: Payload Power Requirements

Assuming a baseline of full use of the band (i.e. 24 transponders of 36 MHz bandwidth) and use of the maximum allowed transmit power, the required satellite primary power depends on the following factors only:

- Transponder efficiency
- Antenna efficiency
- Coverage area
- Frequency band(s) covered

Table III-10 gives the total payload power requirement for CONUS coverage, assuming amplifier efficiencies appropriate for 1985 and 1995 satellites. There are 24 C-band transponders of 36 MHz bandwidth and 8.5 W, and 16 Ku-band transponders of 54 MHz bandwidth and 50 W power. Power is included for receivers, switches, and payload control.

The cost of providing power is in the solar cells, the batteries required for eclipse operation, and the thermal control subsystem. An increase in power directly increases satellite mass and cost. Since only one third of its solar cells face the sun at one time, the spinner satellite is less efficient than the three axis satellite design in terms of mass required to supply large amounts of power.

4.10 Reliability

Reliability has the same consideration as lifetime: redundant components increase reliability at the expense of increased satellite mass. Current satellite designs are optimized with regard

Class of Transponder	Price ($M/year)	
	C-Band	Ku-Band
Protected	1.90	3.6
Unprotected	1.40	2.6
Preemptible	.90	1.7

Table III–11: Transponder Price

to probability of failure and redundant components. The degradation curves for the different satellite types have been given in Table II-7.

Transponders are priced in three categories – protected, unprotected, and preemptible – according to degree of protection from failures. Spares are used while available to replace failed components as required for all customers. As further failures occur, first the preemptible and then the unprotected customers are removed regardless of which particular transponder fails.

Table III-11 gives current prices of the different classes of transponders for C-band and Ku-band satellites. A five year lease with monthly payments is assumed. Baselines are a 8.5 W C-band SSPA transponder with 36 MHz bandwidth and a 50 W Ku-band TWTA transponder with 54 MHz bandwidth.

4.11 Time Delay at Launch

A time delay at launch has a relatively large effect on rate-of-return since the satellite capital expenditures have been made but no revenue is being generated. Table III-12 shows the effect on the rate-of-return (DTRR and IRR) of time delays at launch from one month to one year. The 1995 hybrid satellite design was used. A 1% decrease in DTRR is equivalent to an initial capital expenditure of $12 M.

The tax assumption is that the depreciation (ACRS) is written off the first year regardless of whether the satellite is launched that year. The result would be even worse if the time delay were such that the depreciation had to slip to the next fiscal year before being utilized.

Time Delay (months)	Rate-of-Return, %	
	DTRR	IRR
0	21.90	28.06
1	21.50	27.70
3	21.31	26.96
6	21.00	25.84
9	20.65	24.71
12	20.29	23.58

Table III–12: Effect of Launch Delay

Modulation Method	% Increase in Channel Capacity SSPA vs. TWTA
FDM (single access)	4
FDM (multiple access) (2 carriers)	10
FDM (multiple access) (6 carriers)	25
SCPC	50

Table III–13: SSPA Transponder Capacity

4.12 Transponder Type

The greater linearity of the SSPA compared to the TWTA results in increased channel capacity. Table III-13 shows how channel capacity depends on modulation method and access methods. The nonlinear nature of the TWTA requires it to be operated at reduced power when multiple signals are present. The increased linearity of the SSPA results in less intermodulation distortion of other signals.

The improved linearity of the SSPA results in the ability to transmit two television channels through one 36 MHz transponder, and the use of single sideband amplitude modulation (SSB-AM) techniques to transmit as many as 6000 one-way voice channels through one transponder.

Debt Ratio %	Interest Expense $M	Rate of Return IRR %	DTRR %
0	–	17.1	17.7
25	12.6	19.3	18.5
45	22.6	21.9	19.6
50	25.2	22.8	19.9
75	37.7	29.5	22.7
100	50.3	54.9	31.0

Table III–14: Return Versus Debt Ratio

5 Financial Characteristics

The influence of the following financial characteristics on system economic performance is investigated:

1. Debt ratio
2. Insurance
3. Interest rate
4. Period of financing
5. Taxes

5.1 Debt Ratio

Table III-14 shows the effects of varying the percentage of debt (debt ratio) used to finance the capital expenditures for the 1985 Ku-band satellite. The interest expense is stated in incurred economics and the percentage of debt assumed in the Model is 45%.

The result is that a 25 point increase in debt ratio causes a 0.8 point increase in the DTRR and a $12.5 M increase in interest expense. Higher rates of return accompany increased debt levels primarily because equity cash outflows are deferred and the cost of debt is lower than the cost of equity.

By financing, the equity shareholders are able to defer cash outlays for the capital cost of the project. Because all of the cash flows are adjusted for the time value of money, expenditures in beginning periods are worth more than those in later periods. Therefore, by deferring equity cash outlays, total project costs are lowered on a present value basis. This benefit of deferring costs is more than enough to offset the added interest expense, less taxes, arising from the use of debt.

Satellite project risks also increase with debt because the cost of debt is lower than the cost of equity. It is better for shareholders to borrow money from the bank at 11% (5.6% after tax) than to use their own funds which carry an implicit cost of 18% and are not tax deductible.

This sensitivity analysis varies the amount of debt, holding all other economic factors constant, and leads to the conclusion that satellite operators achieve the best return by financing 100% of the project capital cost. This conclusion is not supported by reality, however, since it is rare to find projects 100% leveraged. This is due to the bank's unwillingness to finance most of a project, the higher borrowing rates accompanying higher debt levels, and the increased cost of equity due to increased shareholder risk.

The existence of an optimal capital structure (debt versus equity) for businesses is debatable. Some empirical studies show that returns do increase with leverage. This increase is limited, however, and the assumption is usually made that the optimal capital structure for a particular business is that which is used by its particular industry. The debt ratio of 45% used in this study is representative of the satellite industry, and is assumed to be at an optimal level.

5.2 Insurance

Table III-15 shows the variation of rate-of-return with launch insurance cost for the 1985 Ku-band satellite which has a total cost of $108 M. Insurance cost is calculated using incurred economics.

For 1985 satellites, the average rate is 14%, current quotes for launch insurance are around 30%, and the projection is for rates to return to 20% for 1995 satellites. Rates above 30% lead to self insurance, and rates below 10% are unlikely due to the inherent risk of relatively new space operations.

The potential variation in insurance rates is likely to be 10 points: for example, a reduction from 20% to 10% for use of a safer launch vehicle

Insurance Rate %	Insurance Cost $M	Rate of Return IRR %	DTRR %
0	–	25.0	20.8
5	4.9	23.9	20.4
10	10.2	22.8	20.0
15	16.0	21.7	19.5
20	22.3	20.6	19.1
25	29.1	19.4	18.6
30	36.3	18.2	18.1
35	43.9	17.1	17.6

Table III–15: Return Versus Insurance Cost

Interest Rate %	Interest Expense $M	Rate of Return IRR %	DTRR %
9	11.9	22.2	19.7
11	14.8	21.9	19.6
13	17.7	21.7	19.5
15	20.7	21.4	19.4
17	23.8	21.2	19.3

Table III–16: Return Versus Interest Rate

like the OTV. This would translate to a $12 M savings in insurance cost and a 1 point increase in the DTRR return.

5.3 Interest Rate

Table III-16 shows the results of varying the interest rate for the 1985 Ku-band satellite. The interest expense is stated in incurred economics and relates to the permanent financing. The base assumption in the Model is an interest rate of 11%.

The result is that a two point increase in interest rate causes a 0.1 decrease in the DTRR return, and a $2.9 M increase in interest expense. The small decrease in DTRR is due to the dollar magnitude of interest expense relative to total project cash flows, and the deductibility of interest which makes a 1 point rate increase equivalent to 2 points after taxes.

Period of Financing yrs	Interest Expense $M	Rate of Return IRR %	DTRR %
1	2.9	19.2	18.5
2	5.8	19.9	18.9
3	8.7	20.6	19.2
4	11.7	21.3	19.4
5	14.8	21.9	19.6
6	18.0	22.6	19.8
7	21.3	23.2	20.0
8	24.6	23.8	20.1
9	28.1	24.3	20.3
10	31.7	24.8	20.4

Table III–17: Return Versus Financing Period

Interest rates vary with economic conditions and are difficult to forecast with confidence. The assumptions for interest rates used in the Model is the prime rate at the end of the first quarter of 1986 plus 2 points (11%).

5.4 Period of Financing

Table III-17 shows the results of varying the period of financing for the 1985 Ku-band satellite. The interest expense is stated in incurred economics and the base assumption for period of financing used in the Model is five years.

On the average, a one year increase in period of financing results in a 0.2 point increase in the DTRR and a $3 M increase in interest expense. The DTRR increases despite increased interest expense because a longer period of financing allows the equity shareholder to defer large cash outlays for capital, resulting in lower overall costs on a present value basis (see III-5.1). The potential range of variation for period of financing is thought to be two years, with the Model assumption of five years being the maximum period.

5.5 Taxes

5.5.1 Depreciation

The baseline Model uses accelerated cost recovery (ACRS) depreciation. For purposes of comparison, a straight line depreciation over a period of ten years is analyzed. The result, for the 1985 Ku-band satellite, is a drop in DTRR of 1.4 points.

Accelerated depreciation permits the operator to realize the greatest immediate benefit for tax purposes. By spreading the benefits of depreciation over the life of the satellite, the net income cash flows are considerably smaller than if an accelerated method is elected.

5.5.2 Investment Tax Credit

The investment tax credit (ITC) is a direct reduction in tax liability calculated as a percentage of capital expenditures. It is designed to provide an incentive for capital investment. The Model assumes an 8% ITC taken when the satellite is placed in service.

There is currently proposed legislation to discontinue the ITC. For the Ku-band satellite, removal of ITC results in a tax expense increase of $8.6 M in incurred economics and the DTRR declines 0.9 points.

5.5.3 Loss Carry Forward

Depending on a corporation's capital and operating structures, it may carry forward its losses for tax purposes or pass them through for corporate use. To achieve the maximum return on investment, these losses should be passed to the corporation assuming the corporation has enough profits to offset the losses. The method used by the Model is to assume that the losses are used when incurred.

For purposes of comparison, use of the loss carry forward method was analyzed for the Ku-band satellite and resulted in a 2.9 point decrease in DTRR. Immediate tax loss write-off is much more desirable than loss carry forward.

6 Discussion

The conclusion is that current satellite designs are optimized for their technical characteristics in order to maximize revenues. The trend is to build larger satellites with increased capacity and economies of scale.

Section IV

TECHNOLOGY FORECAST FOR 1995 & DEFINITION OF FSS SYSTEMS

1 Introduction

This section presents the following Task 2 results for 1995 satellites:

- Technology assessment and forecast;
- Description of three FSS systems.

In addition, a large (2,200 kg) high-capacity satellite design is postulated which takes advantage of the launch capacity of the space-based OTV.

The next section (Section V) will use the Financial Model to analyze the performance of the three postulated FSS (fixed satellite service) systems. This will form the baseline for comparison with the Space Station APO Scenarios of Tasks 3 and 4.

2 Technology Assessment

An assessment is made of the expected state-of-the-art status of communications satellite systems and operations for U. S. domestic FSS systems initially entering service in 1995 – initial operational capability (IOC) in 1995. The assessment is constrained to a consideration of business-as-usual satellite system operations employing evolutionary improvements in satellite system technology and the allied field of space transportation. The business-as-usual constraint means that Space Station or space-based operations will be excluded from the assessment. This assessment will be used to develop, in the next subsection, a description of three satellite systems representative of the 1995 state-of-the-art.

The assessment will consider each of the seven communications satellite subsystems:

1. Attitude Control
2. Communications Payload
3. Primary Power
4. Propulsion
5. Structure and Mechanisms
6. Telemetry, Tracking, and Command
7. Thermal Control

Also assessed will be the following:

8. Space transportation

2.1 Attitude Control Subsystem

The business-as-usual attitude and orbit control subsystems contain a variety of autonomous and manual control modes. During basic on-orbit operation, as many as 20 people (over three shifts) are required for manual control of attitude and orbit parameters. The number of people could be reduced to 6 if some basic jobs could be made autonomous. The station keeping or orbit control, which has the highest manual control requirements, could be made autonomous by advances being made in navigation and computer software and hardware. The reliability of this type of autonomy is currently being studied through various programs.

Use of the TDRSS relay satellites would allow contact to be kept with the satellite even when on the other side of the earth from the control station. Use of the planned global positioning system (GPS) network of satellites will allow constant and more accurate position determination. Together, GPS and TDRSS will simplify the support required for initial positioning in orbit and for attitude determination during the lifetime of the satellite.

The recently-developed ring laser gyroscope has several advantages over conventional gyros:

- Higher accuracy;
- Reduced calibration time; and
- Quicker start-up.

At present the ring laser gyro is heavier, uses more power, and is more expensive than a conventional gyro. However, developments of this technology are expected to overcome these problems by 1995. It is forecast that the ring laser gyro will be used rather than the digital integrated rate assembly (DIRA) for sensing of satellite attitude.

2.2 Communications Payload

Due to development of higher strength materials and increased compactness of electronic components, a 15% mass reduction for the payload is projected for 1995.

2.2.1 Antennas

Modest technical advances are projected over the next decade for the antenna subsystem, but they will be offset by the increased performance requirements imposed by closer orbital spacings. Increased component efficiency will be offset by the reduced antenna efficiency of tapered illumination functions required to control sidelobes.

Antenna subsystem development costs will be reduced by improved analysis programs that allow skipping of the breadboard antenna design step.

Antenna manufacturing costs will be reduced by near field range facilities which allow faster and more accurate adjustment of the antenna subsystem.

The development of higher strength materials will allow a 10% reduction in antenna subsystem mass for 1995. However, increased frequency

Frequency Band	Efficiency, %	
	1985	1995
C	48	63
Ku	37	53
Ka	29	45

Table IV–1: TWTA Efficiency

reuse will require smaller beam sizes which require larger diameter antennas. Use of the Shuttle limits the diameter of a solid reflector to 15 ft (4.5 m), which corresponds to 1.25° C-band and 0.30° Ku-band beam sizes. The Ka-band reflector size is limited to 4 m, corresponding to a 0.3° beam size, by the overall satellite pointing accuracy.

2.2.2 Transponders and Receivers

Most significant advances in the transponder subsystem will be in the area of better device performance – lighter and more efficient traveling wave tube amplifiers (TWTA's) and solid state power amplifiers (SSPA's) and better noise figure low noise amplifiers (LNA's).

Table IV-1 gives TWTA efficiency (dc to rf power) predictions for 1985 and 1995 satellites. The 50 W per transponder required at Ku-band will be supplied by a TWTA with an expected 10 year lifetime for 1995.

Solid state power amplifiers (SSPA) will be available with 10 W per device at C-band and 35% efficiency for 1995. SSPA have advantages of increased reliability and lifetime, and much less mass than the equivalent TWTA. A satellite with 36 10 W C-band channels would require 1030 W of dc power for SSPA's versus 570 W for TWTA's. For 1995, SSPA's will be preferred for C-band use.

LNA's using GaAS Fet's will be available for 1995 with 2.5 dB noise figures, a 1 dB improvement from 1985. The most significant change for receivers will be in a 50% mass reduction due to large scale integration techniques.

The development of dielectric filters and oscillators will allow a great reduction in transponder subsystem mass.

Improvements in modulation techniques, particularly digital coding schemes, will allow more efficient use of the available bandwidth.

MMIC technology has the potential to greatly reduce payload mass and add capability, but is judged to be immature for commercial satellite applications in 1995.

2.2.3 On-Board Processing

The most dramatic change in technology could be in the area of on-board signal processing due to advances in VHSIC technology and high speed digital control systems. Benefits can be achieved in the areas of:

- Increased connectivity;
- Increased capacity;
- Increased communications link efficiency;
- Increased flexibility.

Increased connectivity via switch matrices is postulated for 1995 satellites, but on-board signal demodulation is judged to be immature technology.

2.3 Primary Power

2.3.1 Batteries

The standard method of power storage in commercial satellites has been the nickel cadmium (NiCad) battery. In 1984, the Intelsat V and G-Star satellites became the first commercial satellites to use nickel hydrogen (NiH) batteries. The main advantage of the NiH over the NiCad battery is its higher depth of discharge (DOD) which effectively increases its power to weight ratio.

The sodium sulfur (NaS) battery is presently under development and promises to have a power to weight ratio three times the NiCad battery. Although the NaS battery operates at a temperature of 350° C, the required technology exists. Table IV-2 compares battery performance. The NaS battery is the preferred technology for 1995 satellites.

Type	Year	DOD (%)	Power/weight (W hr kg^{-1})
NiCad	1985	55	21.3
NiH	1985	70	24.5
NiH	1989	70	31.0
NaS	1992	70	58.0
NaS	1995	70	70.0

Table IV–2: Battery Comparison

2.3.2 Solar Cells

Current practice uses silicon (Si) solar cells with 13.5% BOL efficiency. Developments are underway to reduce cell thickness and thus mass. Although thin cells are more expensive to manufacture, the reduced mass will give a lower overall cost in geosynchronous orbit.

The gallium arsenide (GaAs) cell, currently under development, has a 21% BOL efficiency and is relatively impervious to radiation, but is 2.5 times heavier than silicon and much more expensive. By 1995 GaAs may be equal to Si cells for space applications (same on-orbit cost for equal capacity), but will only be used when area available for solar cells is limited (as for a high power spinner satellite).

The 1995 solar collector technology for commercial satellites will remain silicon, but collector mass should be reduced by 25% for similar capacity systems.

2.4 Propulsion Subsystem

Two types of propulsion systems are being used today:

- Hydrazine station keeping system plus solid-propellant apogee motor;
- A bipropellant system [nitrogen tetraoxide (N_2O_4) and monomethylhydrazine (MMH)] used for both station keeping and apogee motor firing.

The hydrazine thruster has the advantage of being able to supply smaller force-time increments of thrust. However, the biprop system results in mass savings due to the higher specific impulse of the fuel and is the preferred technology, allowing less fuel mass or longer station keeping time with a given fuel mass. The biprop technology will be assumed for 1995 satellites.

Hydrazine thruster performance can be improved by heating the fuel at the thruster. Devices known as augmented catalytic thrusters (ACTs) will be available with 50% more specific impulse than today. However, significant electric power is required to operate these thrusters (approximately 10 kW for a 1 N thruster). Systems requiring solid apogee motors will use this technology for station keeping, but bipropellant systems remain the preferred technology.

2.5 Structure and Mechanisms

Business-as-usual satellite structures are primarily constructed of aluminum or aluminum honeycomb materials with two main exceptions:

- If the satellite has a mass problem due to launch vehicle constraints, some structure may be manufactured from either graphite fiber reinforced plastic (GFRP) or beryllium.
- Parts of the satellite critical to thermal distortions, such as antenna related structures, are usually constructed from GFRP due to its extremely low coefficient of thermal expansion.

However, the additional expense of these exotic materials will continue to keep their use to a minimum for commercial communications satellites.

Higher strength graphite materials will be available in 1995, which should reduce mass by 10%. However, for the major part of the satellite, there will be no use of new structural technology.

Satellite appendages are typically deployed with one-shot spring motor devices or electromechanical actuators. No significant changes are expected for 1995.

2.6 TT&C Subsystem

Little technology change is expected in the telemetry, tracking, and command (TT&C) subsystem for 1995 satellites. At present TT&C takes place at C-band. However, a number of new satellites are planning to use Ku-band since C-Band is becoming saturated with users. Likewise, as more satellites shift to Ku-band, there may need to be a shift to Ka-band with consequent rain attenuation problems. For 1995, C and Ku bands will be adequate.

2.7 Thermal Control

Present satellites use passive thermal control plus heater augmentation. Passive radiators are mounted on the north or south-facing panels of a 3-axis satellite or on the despun portion of a spinner satellite. These systems are relatively inexpensive, but are heavy and limited in capacity per radiator area.

New generation satellites may incorporate heat pipes with passive or active pumping to reduce mass and improve thermal dissipation capacity. A single phase pump system using freon fluid has been demonstrated which is efficient up to 4 kW dissipation. A pumped heat pipe system has more accurate temperature control than a passive system, but this is not a critical factor for communications systems which can typically tolerate $\pm 50°$ C.

The passive heat pipe rather than the pumped system is the preferred technology for 1995 FSS systems. It has:

- Greater design maturity;
- Higher reliability and life;
- Less complex integration.

Heat pipes are imbedded within the honeycomb structure of the equipment panel for best efficiency, minimum system weight, and less complex spacecraft integration.

Radiators fixed to the body of the spacecraft rather than deployable radiators are preferred due to their lower weight and cost, and higher reliability. Deployable radiators would be used only if adequate area does not exist for fixed radiators.

2.8 Space Transportation

The Ariane launch vehicle places the satellite in a highly elliptical orbit known as a geosynchronous transfer orbit (GTO) with a perigee altitude of 200 km and an apogee altitude of 36,000 km. A high thrust apogee kick motor (AKM) is then used to circularize the GTO orbit. Finally, fine orbit adjustments are made.

The Space Transportation System (STS) or Shuttle places a payload in low earth orbit (LEO) at an altitude of 260 km. Further means are then required to transport the payload to geosynchronous earth orbit (GEO), which is a circular orbit of 36,000 km altitude. Table IV-4 gives transportation alternatives for transport from LEO to GTO and from LEO to GEO. All of these alternatives are relatively costly (approximate costs given in 1986 dollars).

Another alternative method of transportation from LEO (or GTO) is the integral perigee stage, which is controlled directly from the satellite. This results in lower mass and significantly reduced launch costs.

It is anticipated that these means of space transportation will not change for 1995.

A new development will be the ground based orbital transfer vehicle (OTV) which is scheduled to become operational in 1995. If the current prices projected for its use are correct and fuel costs do not become excessive, the STS & OTV combination will become the least expensive alternative.

The space-based (SB) OTV is scheduled to become operational in 1998, and should have a dramatic effect on upper stage launch costs. The SB-OTV will be based at the Space Station and will not have to be carried up from earth for each use. It will be reusable and return from GEO orbit via aerobraking to conserve fuel. The capacity of the SB-OTV is planned to be 12,000 kg, which will allow much larger satellites to be put into orbit.

2.9 Summary of Technology Developments

The anticipated technology developments for each subsystem are summarized in Table IV-5 along with the anticipated technical benefits. Cost savings due to the improved technologies will be incorporated into the Financial Model results of Section V.

Satellite Type	Payload	Task 1	Task 2	Task 3	Task 4
HS376	C-band	•			
HS393	Ku-band		•	•	•
K2	Ku-band	•	•		
Spacenet	C & Ku	•			
Fordsat	C & Ku		•	•	•

Table IV-3: FSS Systems

3 Description of Three FSS Systems for 1995

This subsection presents descriptions based on the preceding technology assessment of three representative systems incorporating the forecasted improvements. Section V will use the Financial Model to determine economic performance.

Table IV-3 summarizes the satellite types used for the different phases of the study. The Task 1 Model Validation relates to 1985 satellites, while Tasks 2, 3 and 4 relate to 1995 satellites. The selected satellites types are named according to the present type they most nearly resemble. However, they are generic types and payload and bus do not necessarily match the existing or planned satellite of that name.

Table IV-6 compares the characteristics of the three 1995 satellites. Cost includes 12% G&A and 12% fee.

3.1 Spinner Satellite System

The spin stabilized satellite is similar to the Hughes HS-393 design. Table IV-7 presents a summary of its characteristics. Most prominent is the enhanced payload possible from the use of 1995 technology.

Type	Manufacturer	Propulsion	Capacity (kg) Leo-Gto	Capacity (kg) Leo-Geo	Status	Cost ($M)
Pam D	McDonnell Douglas	Solid	1,250	0	Operational	8
Pam D II	McDonnell Douglas	Solid	1,842	-	Operational	9.5
TOS	OSC	Solid	5,942	-	In qualification	20
TOS/AMS	OSC	Solid/liquid	8,437	2,950	In development	$\geq$ 30
Delta	Astrotech	Liquid	-	-	In development	$\geq$ 22
IUS	Boeing	Solid	-	2,268	Operational	30
Centaur G	General Dynamics	Cryogenic	11,022	4,536	Progam stopped	50
Centaur G′	General Dynamics	Cryogenic	11,160	5,988	Program stopped	50

Table IV–4: Available Orbital Transfer Rockets

Category	Change	Benefit
Structure	None	
Thermal	Passive heat pipes	Reduced mass of thermal subsystem. Higher thermal dissipation.
Propulsion	Bipropellant system	Reduced fuel mass.
Attitude Control	Use of GPS & TDRSS	More accurate and faster position determination.
	Ring laser gyro	Increased reliability, less calibration time.
Power	NaS batteries	Improved power/weight ratio.
	Thinner Si solar cells	Reduction in mass.
	GaAs solar cells	Greater efficiency (21% vs 13%)
TT&C	None	
Comm. Payload	Better design tools	Reduced development time & cost.
	Near field testing	Reduced testing time.
	More efficient TWTA's	Less power required.
	SSPA's at C-band	Greater reliability and lifetime, less mass
	Improved modulation	More efficient use of given bandwidth.
	VHSIC & microprocessors	Better capacity for processing and switching.
	High strength materials	15% mass reduction for antenna subsytem
	Large scale integration	15% mass reduction for electronic components
Space Transport	Ground-based OTV	Reduced launch costs.
	Space-based OTV	Greater launch capacity.

Table IV–5: Satellite Technology Developments (1995 Launch)

	Spinner	Ku-Band	Hybrid
Baseline satellite	Hughes HS-393	RCA K2	Ford FS-1300
Design life (yr)	10	10	10
BOL mass (kg)	1377	1044	1540
Payload mass (kg)	261	261	342
– Antenna (kg)	29	29	52
– Transponder (kg)	232	232	290
EOL power (W)	2900	3000	4200
Stabilization	Spin	Three-axis	Three-axis
Frequencies	Ku-band	Ku-band	C and Ku-bands
Number of transponders:			
– C-band			24
– Ku-band	24	24	24 & 6
Transponder bandwidth:			
– C-band (MHz)			36
– Ku-band (MHz)	54	54	36 & 72
Transponder power:			
– C-band (W)			10
– Ku-band (W)	50	50	35
Antenna coverages:			
– C-band			2
– Ku-band	3	3	3
Satellite EIRP (Conus):			
– C-band (dBW)			36
– Ku-band (dBW)	46	46	46
Launch vehicle(s):	Ariane IV	Ariane IV	Ariane IV
	STS/PAM D II	STS/PAM D II	STS/Ford perigee
Satellite Cost ($M, 1985)	54.2	50.9	64.6

Table IV–6: Summary of 1995 Satellite Characteristics

Manufacturer & model: Baseline satellite name: EIRP (Conus): Lifetime: On-board switching: Launch vehicle:	Hughes HS-393 Galaxy K 46 dBW 10 yr Among coverage regions Ariane 4 or STS
Frequency band and bandwidth: – receive: – transmit:	Ku-band, 500 MHz 11.7 – 12.2 GHz 14.0 – 14.5 GHz
Antenna – type: – number: – size: – mass: – feed array: – coverage (3 beams): – polarization:	 Offset parabolic, dual gridded 1 2.44 m 29 kg 2 each 80 elements CONUS and E & W CONUS Dual linear
Transponders – number: – power: – bandwidth: – TWTA redundancy: – receiver redundancy: – mass: – dc power:	 24 50 W 54 MHz 5 for 4 6 for 3 232 kg 2,522 W
Spacecraft – type: – size (stowed): – mass, BOL: – power, EOL at summer solstice: – primary power: – batteries: – attitude and station keeping: – attitude pointing accuracy: – apogee motor:	 spin stabilized dia = 3.64 m, length = 3.35 m 1377 kg 2900 W Solar cells (Si) NaS Bipropellant thrusters ±0.05° Liquid propellant

Table IV–7: Spin-Stabilized Satellite Characteristics (1995)

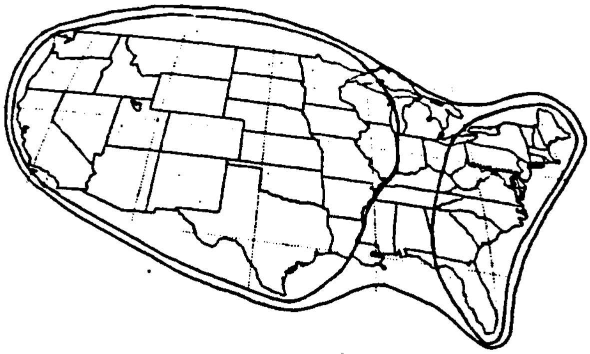


Figure IV–1: Ku-Band FSS Coverage Regions

3.1.1 Ku-Band FSS Payload

This payload is similar to the Scenario II, Ku-band FSS concept developed under NASA Contract No. NAS3-24235, *Communication Platform Payload Definition Study.* It has three times frequency reuse with one CONUS beam, one eastern beam, and one western beam, all interconnected via electronic switches.

The payload features a dual gridded reflector to obtain the polarization purity required for reuse and two 80 element feed arrays. The reflector assembly is stacked with a slight offset in focal point to give a physical separation of the feed assemblies. One feed assembly is for the horizontal and the other for the vertical polarization. The feed array is connected to a diplexer which separates the receive and transmit channels on the basis of their different frequencies.

Figure IV-1 shows the antenna coverage regions; full CONUS is horizontal polarization and the east and west beams are vertical polarization. The spacial separation between east and west beams is necessary to achieve 25 dB co-polarization isolation. Table IV-8 gives predicted edge-of-coverage (EOC) antenna gains.

Each coverage region has eight 54 MHz bandwidth transponders, giving a total of 24 channels. The receiver output for each coverage region is fed to an input multiplexer which subdivides the 500 MHz IF band into eight channels. The three input multiplexers are followed by eight 3 x 3 switch matrices in order to permit signals in any uplink channel to be retransmitted to any of the three coverage regions.

Coverage	Gain (dBi)
Full CONUS	29.0
East Half CONUS	35.2
West Half CONUS	29.7

Table IV–8: Ku-Band Predicted Antenna Gain

The receiver preamplifiers are low noise GaAs FET's with 2.5 dB noise figure. Monolithic gain block amplifiers and dielectric oscillators will be used to reduce size and power consumption of the receiver. The 11 GHz input multiplexers will use dielectric resonators to reduce size and mass by a factor of three. TWTA efficiency of 53% overall (TWT plus power supply) and 10 year lifetime is projected.

3.1.2 Other Design Features

The large payload power requirement of 2,500 W poses a problem for this spinner satellite design, in terms of area for solar cells and waste heat radiators. However, high efficiency GaAs solar cells could be used to allow 50% more power to be obtained from the same solar cell area, but at the expense of added mass.

3.2 Ku-Band Satellite System

The 1995 Ku-band satellite is a 3-axis design similar to the RCA K-2. Its characterisitics are shown in Table IV-9.

3.2.1 Ku-Band FSS Payload

This is the same payload as described in subsection 3.1.1 for the Spinner satellite.

3.2.2 Other Design Features

The 3-axis satellite design allows for additional solar cell area. Use of thin Si solar cells will lead to overall mass reduction.

Manufacturer & model:	RCA Americom, K2
Baseline satellite name:	Satcom K2
EIRP (Conus):	46 dBW
Lifetime:	10 yr
On-board switching:	Among coverage regions
Launch vehicle:	Ariane 4 or STS/PAM D2
Frequency band and bandwidth:	Ku-band, 500 MHz
– receive:	14.0-14.5 GHz
– transmit:	11.7-12.2 GHz
Antenna	
– type:	Offset parabolic, dual gridded
– number:	1
– size:	2.44 m
– mass:	29 kg
– feed array:	2 each 80 elements
– coverage (3 beams):	CONUS and E & W CONUS
– polarization:	H and V, linear
Transponders	
– number:	24
– power:	50 W
– bandwidth:	54 MHz
– TWTA redundancy:	5 for 4
– receiver redundancy:	6 for 3
– mass:	232 kg
– dc power:	2,522 W
Spacecraft	
– type:	3-axis stabilized
– size (bus):	1.57 x 2.18 x 1.77 m
– mass, BOL:	1200 kg
– power (EOL) at summer solstice:	3000 W
– primary power:	Solar cells (thin Si)
– batteries:	4 NaS, 150 Ah
– thermal control:	Heat pipes
– attitude and station keeping:	Hydrazine thrusters (ACTS)
– attitude pointing accuracy:	±0.07°
– apogee motor:	Solid propellant

Table IV–9: Ku-Band Satellite Characteristics (1995)

Manufacturer & model: Baseline satellite name: EIRP (Conus): Lifetime: On-board switching: Launch vehicle:	Ford Aerospace FS-1300 Ford Hybrid Satellite 36 dBW C-band, 44 dBW Ku-band 10 yr Among coverage regions, also C- and Ku-bands interconnected Ariane 4 or STS/Ford perigee
Frequency band and bandwidth: – receive: – transmit:	C-band 500 MHz, Ku-band 500 MHz 5.925-6.425 and 14.0-14.5 GHz 3.700-4.200 and 11.7-12.2 GHz
Antenna – type: – number: – size: – mass: – coverage (2 C and 3 Ku beams): – polarization:	 Offset parabolic, dual-gridded 2 1.4 m x 1.8 m C-band, 2.44 m Ku-band 17 kg C-band, 35 kg Ku-band CONUS and E & W CONUS H and V linear for both bands
Transponders – number of C-band: – power at C-band: – bandwidth at C-band: – SSPA redundency (C-band): – receiver redundency (C-band): – number of Ku-band: – power at Ku-band: – bandwidth at Ku-band: – TWTA redundency (Ku-band): – receiver redundency (Ku-band): – mass: – dc power:	 24 10 W 36 MHz 5 for 4 4 for 2 30 33 W 36 MHz (24), 72 MHz (6) 5 for 4 4 for 2 72 kg C-band, 290 kg Ku-band 660 W C-band, 2,780 W Ku-band
Spacecraft – size (stowed): – mass, BOL: – power (EOL) at summer solstice: – primary power: – batteries: – attitude and station keeping: – attitude pointing accuracy: – apogee motor	 2.5 m x 1.88 m x 2.64 m 1540 kg 4000 W Solar cells (thin Si) 4 NaS, 232 Ah (total) 3-axis stab, biprop thrusters $\pm 0.1°$ Liquid propulsion

Table IV–10: Hybrid Satellite Characteristics (1995)

Function	Coverage Region	Gain (dB)	Pol.
Transmit	Conus	27.0	V
Transmit	Alaska	27.0	V
Transmit	Conus + Alaska	25.0	V
Receive	Conus + Alaska	25.0	V
Transmit	Conus	27.2	H
Transmit	Hawaii	31.8	H
Transmit	Puerto Rico	29.7	H
Transmit	Conus + Hawaii	25.1	H
Transmit	Conus + PR	25.1	H
Receive	Conus+HI+PR	25.1	H

Table IV–11: C-Band Antenna Predicted Gain

3.3 Hybrid Satellite System

The 1995 hybrid satellite design is a 3-axis satellite similar to the Ford Satellite design. Its characteristics are summarized in Table IV-10. The payload includes both C and Ku-band transponders, which are interconnectable and therefore of the same bandwidth (36 MHz).

3.3.1 C-Band FSS Payload

This payload is similar to the Scenario II C-band FSS concept developed under NASA Contract No. NAS3-24235, *Communication Platform Payload Definition Study.* It provides two times frequency reuse via horizontal and vertical polarized beams. The coverage is full CONUS with selected coverage for Alaska, Hawaii, and Puerto Rico.

The C-band antenna consists of a dual-gridded offset-fed reflector and two 7-element feed arrays for each polarization. Both transmit and receive bands use the same feed array. Antenna size is 1.4 m x 1.8 m. Table IV-11 gives the calculated edge-of-coverage gains for the vertical and horizontally polarized antennas.

The C-band transponder uses SSPA's with 35% dc to RF power efficiency. The receiver has low noise GaAs FET's with 1.5 dB noise figure, monolithic gain blocks, and dielectric oscillators. The multiplexers will use dielectric resonator filters.

3.3.2 Ku-Band FSS Payload

This is the same payload as described in subsection 3.1.1 for the Spinner satellite, except that transponder bandwidth is now 36 MHz and thus there are a total of 36 transponders (12 per 500 MHz band coverage region).

3.3.3 Other Design Features

The use of 36 MHz bandwidth at C and Ku-bands is to allow interconnection between bands, i.e. uplink at Ku-band and downlink at C-band. There is also provision for switching of transponders among the different coverage regions.

3.4 Comparison of Systems

The spinner and Ku-band systems carry the same payload, but the spinner design requires 15% greater mass. The hybrid system is larger yet with 54 transponders versus the 24 transponders of the other two systems.

4 Large Satellite System

A 2,200 kg (5000 lb) satellite design is postulated which takes advantage of the space-based orbital transfer vehicle (SB-OTV). This satellite is named "Hectosat" after its 100 transponder payload.

The satellite is at the upper mass limit of the study. Satellites of larger than 5,000 lb are considered platforms and are outside the scope of this study.

The motivation for this design is the SB-OTV which can more efficiently transfer mass from LEO to GEO. The SB-OTV will be based in LEO at the Space Station and is reusable. Its mass doesn't need to be lifted from earth to LEO for each launch. It uses atmospheric aerobraking to reduce fuel costs for return from GEO to the Space Station.

4.1 Satellite Design

The satellite is a three axis design of 2,144 kg mass and 3,100 W primary power. It has a payload of 108 Ku-band transponders. Table IV-13 gives the characteristics of the design.

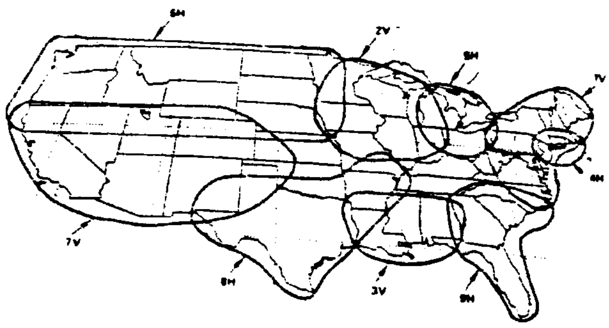


Figure IV–2: Ku-Band FSS Coverage Regions

Beam	Gain (dBi)	Power (dBW)	(W)
1	39.9	6.6	4.6
2	40.1	6.4	4.4
3	40.9	5.6	3.7
4	47.4	-0.9	.8
5	39.7	6.8	4.8
6	33.4	13.1	20.5
7	35.8	10.7	11.8
8	36.5	10.0	10.0
9	39.0	7.2	5.7

Table IV–12: Power Requirements for Beams

4.2 Payload

Hectosat uses the Scenario V Ku-band FSS concept developed under NASA Contract No. NAS3-24235, *Communication Platform Payload Definition Study.* It provides nine times frequency reuse via horizontal and vertical polarized regional beams over CONUS (see Figure IV-2). Its capacity is three times the Ku-band payload on the spinner and Ku-band satellite designs. Transponder bandwidth is 36 MHz versus the 54 MHz of the previously used Scenario II Ku-band concept.

The payload features a 4.6 m (15 ft) dual-gridded reflector assembly for the spacial resolution and polarization purity required for frequency reuse. Table IV-12 shows the projected antenna gain and amplifier power levels necessary to maintain a 46 dBW EIRP with single carrier operation.

As described in the *Communication Platform Payload Definition Study,* this payload addresses voice trunking traffic and data trunking traffic. Single side band (SSB) modulation techniques allow a total voice traffic capacity of 519,000 half voice circuits. Satellite switched time division multiple access (SS-TDMA) is used on 12 transponders to give a data trunking traffic capacity of 519 Mb/s.

The coverage and interconnectivity of this system has been designed to match the traffic mix forecasted for the future by region. Traffic balancing is such that the fill factor for the 108 transponders is 0.77. Thus the utilization factor input to the Model is 77%. (Note that transponders are not sold as entities in this system. Rather parts of nine transponders are used by each trunking location, depending on volume of traffic and destination.)

4.3 Launch Vehicle

The 2,144 kg BOL mass would require the IUS or Centaur upper stage (see Table IV-4) to be used with a Shuttle launch for a business-as-usual scenario (no Space Station). The economics of a space-based OTV should be much better, and will be analyzed in Section VII.

Baseline satellite name:	Hectosat
EIRP (Conus):	46 dBW
Lifetime:	10 yr
On-board switching/interconnectivity:	Among coverage regions
Launch vehicle:	STS and Centaur or OTV upper stage
Frequency band and bandwidth:	Ku-band; 500 MHz
– receive:	14.0-14.5 GHz
– transmit:	11.7-12.2 GHz
Antenna	
– type:	Offset parabolic, dual-gridded
– number:	1
– size:	4.6 m
– mass:	161 kg
– coverage (9 beams):	9 regional beams
– polarization:	H and V linear for both bands
Transponders	
– number:	108
– power:	20 W maximum; 8 W average
– bandwidth:	36 MHz
– SSPA redundency:	5 for 4
– receiver redundency:	4 for 2
– mass:	586 kg
– dc power:	2,700 W
Spacecraft	
– size (stowed):	2.6 m x 1.9 m x 2.8 m
– mass, BOL:	2,144 kg
– power (EOL) at summer solstice:	3,100 W
– primary power:	Solar cells (thin Si)
– batteries:	4 NaS, 45 Ah
– attitude and station keeping:	3-axis stab, hydrazine thrusters
– attitude pointing accuracy:	±0.05°
– apogee motor	None

Table IV–13: Large Satellite Characteristics (1995)

Section V

BASELINE ECONOMIC PERFORMANCE

1 Introduction

This section presents the Task 2 results on the determination of the economic performance of the business-as-usual scenario for IOC 1995, as defined in Section IV. The Financial Model results for the three FSS systems forms the baseline for comparison with the Space Station APO Scenarios of Tasks 3 and 4.

In addition, a large (2,200 kg) high-capacity satellite design which takes advantage of the launch capacity of the space-based OTV is analyzed. The large satellite is called "Hectosat" after its 100 transponder payload.

The economic performance for the following four 1995 satellite types is presented:

- Ku-band spin-stabilized satellite;
- Ku-band 3-axis satellite;
- Hybrid (C and Ku-bands) 3-axis satellite;
- Large Ku-band 3-axis satellite.

The Financial Model results for the 1985 satellite designs are given in Subsection II-5 and Appendix A.

2 Methodology

The following methodology is used to obtain the 1995 baseline satellite economic performance:

- Start with 1985 satellite designs;
- Predict 1995 technology;
- Evolve 1985 satellites to 1995;
  - A 50% increase in number of transponders on the same size satellite is possible. This allows a 50% increase in communications capacity and revenues (1985 Ku-band to 1995 Ku-band 3-axis design).
- Use the Financial Model to calculate the 1995 satellite system initial rate-of-return. The DTRR (dual terminal rate-of-return) averaged 4.4% higher for the 1995 than the 1985 returns as shown in Table V-1.
- Adjust the 1995 transponder price until the average 1995 return equals the average 1985 return. This requires iteration of the Financial Model.
  - The logic for this step is that market forces will eventually push the return down to the original level.
  - This results in a 33% decrease in the basic transponder price from \$1.9 M to \$1.27 M. This is equivalent to a 4.1% per year transponder price reduction for 10 years.
- The result is the baseline 1995 satellite economic performance as shown in the "Final" column of Table V-1 and described in the following subsections.

Table V-1 gives the dual terminal rate-of-return (DTRR) for the four satellite types that are analyzed. The 1985 column gives the Financial Model results for the 1985 IOC satellites with basic transponder price (C-band, 36 MHz) of \$1.9 M per year.

The "initial" 1995 returns are for the 1995 satellite designs (50% more capacity) and the

Satellite Design	DTRR Return, %		
	1985	1995	
		Initial	Final
C/Ku Spinner	18.1	23.4	18.9
Ku 3-axis	19.8	23.3	18.8
Hybrid 3-axis	21.9	26.5	21.9
Large 3-axis	–	29.6	25.1

Table V–1: DTRR for Satellite Systems

Satellite Design	Cost ($M 1985)	
	1985	1995
C/Ku Spinner	76.5	115.1
Ku 3-axis	104.3	116.8
Hybrid 3-axis	83.1	138.8
Large 3-axis	–	215.4

Table V–2: Capital Costs for Satellites

same basic transponder price. The "final" 1995 returns were adjusted 4.4 points lower so that the average return equals the average 1985 return. This required a 33% decrease in basic transponder price.

The Large satellite is a 1995 design. Its "initial" and "final" returns are 29.6% and 25.1% respectively. The higher return implies that transponder prices will be further reduced.

Table V-2 gives the capital costs of the baseline satellites. The greater costs of the 1995 satellites are due to the increased number and power of the transponders.

3 Ku-band Spinner System

The nine pages of Table B-1 in Appendix B give the Model results for the Ku-band spin-stabilized satellite. The DTRR is 18.9% (after the 33% transponder price reduction) with a total capital expenditure of $115.1 M.

The satellite bus costs are derived from the CS-2 program at Ford Aerospace. The Ku-band payload costs are derived from another program. By varying the parameters against these costs and converging on the known costs, the Price H output is calibrated. The satellite costs for the Model are derived by altering the parameters to reflect a HS-393 design utilizing 1995 technology. The other capital costs are developed from current Ford Aerospace experience or published prices. Since the component capital requirements are validated, the Model itself is also considered to be validated.

4 Ku-Band 3-Axis System

The nine pages of Table B-2 in Appendix B give the Model results for the Ku-band 3-axis satellite. The DTRR is 18.8% (after the 33% transponder price reduction) with a total capital expenditure of $116.8 M.

The costs are based on the Price H output as a result of altering the 1985 K2 parameters to reflect the predicted 1995 technology.

5 Hybrid 3-Axis System

The nine pages of Table B-3 in Appendix B give the Model results for the hybrid 3-axis satellite. The DTRR is 21.9% (after the 33% transponder price reduction) with a total capital expenditure of $138.8 M.

The costs are derived from the Ford Satellite program, but are somewhat generalized. By first calibrating against the currently known satellite and then altering the parameters to reflect the 1995 technology, the Price H satellite costs are considered validated.

6 Large Satellite System

The nine pages of Table B-4 in Appendix B give the Model results for the large satellite with Shuttle launch and Centaur upper stage. The DTRR is 29.6% after the 33% transponder price reduction and application of the 0.77 utilization factor as discussed in Subsection IV-4.2. The total capital expenditure is $215.4 M.

A target DTRR return of 23% is used for the large satellite. The one point premium over the hybrid system is judged to be a necessary incentive for such a large system with its concentration of risk. To reach this target return, a further 18% reduction in transponder price (from \$1.27 M to \$1.04 M) would be required.

The implication is that the large satellite system can either be more profitable than the three business-as-usual cases or that transponder prices can be reduced. Market forces will cause more large satellites to be built with their better economic performance, and transponder prices will eventually be reduced.

7 Discussion

There is little to choose between the capital costs and rates of return for the spinner and 3-axis Ku-band systems. However, due to its greater number of transponders, the hybrid system has a 3% greater rate of return.

This is achieved without selling any cross-connected transponders; i.e. transponder prices are based on all C and all Ku-band sales. As discussed in Subsection III-4.8, sales of hybrid pairs of transponders bring a 30% premium and would further increase the return. For the purposes of this analysis, we take the conservative assumption that revenues from sales of hybrid pairs will be offset by a decrease in utilization of the remaining "wrong way" pairs.

The impressive results for the large satellite are due to economies of scale. The implication is clearly that this is the satellite design of the future. A 18% transponder price reduction from the best performing 1995 satellite is achieved, and a 45% price reduction from the 1985 satellite systems.

Section VI

NEW SPACE-BASED ACTIVITIES

1 Introduction

This section presents the Task 3A results in postulating and defining new or enhanced space-based Activities, Procedures, and Operations (APOs) and associated satellite system designs that have the potential to achieve future communications satellite operations in geostationary orbit with improved economic performance.

Selection has been made of the most promising space-based APOs that have the potential to achieve future communications satellite operations in geosynchronous orbit with improved economic performance compared to the business-as-usual scenario for 1995.

For each APO, the functional description is followed by three paragraphs:

1. Scenario describing sequence of operations with the APO;
2. Requirements placed on the communications satellite, including changes in satellite system design to accommodate the new APOs;
3. Requirements placed on the Space Station and its supporting equipment:
   - Functional and technical requirements
   - Support equipment includes the Orbital Maneuvering Vehicle (OMV), Orbital Transfer Vehicle (OTV), Remote Manipulator System (RMS) on Shuttle, and the Mobile RMS (MRMS) on the Space Station.

The types of requirements include characteristics and capabilities, facilities, interfaces, operational timelines and schedule constraints, special equipment, and internal and external vehicular activity (IVA/EVA) skill types.

These APOs can be combined for advanced scenarios, and in some cases may require another APO to become possible.

Subsection 2 defines eleven APOs, and Subsection 3 discusses the impact on the design of the satellite.

2 Postulation of APOs

The criteria for selection of the APOs are increased communications satellite technical and economic performance. The selection of APOs is made based on predicted available technology and judgment of economic value.

The eleven APOs described in subsections 2.1 to 2.11 are as follows:

1. Emergency retrieval from LEO
2. Ground-based Orbital Transfer Vehicle (OTV) launch to geostationary transfer orbit (GTO)
3. Ground-based OTV launch to geosynchronous earth orbit (GEO)
4. Deployment of appendages at shuttle
5. Space-based OTV launch to GTO
6. Space-based OTV launch to GEO
7. Deployment of appendages at Station
8. Checkout at Space Station
9. Fueling at Space Station
10. Assembly at Space Station

11. Servicing/replacement for GEO satellites
    - Transport to low earth orbit (LEO) for servicing
    - Servicing in GEO

The APOs are listed in order from simplest to most complex, which is approximately the same as chronological for availability.

APOs 2 to 4 use the Ground-Based (GB) OTV and thus would be performed directly from the Shuttle without need for the Space Station. The only difference between APOs 2 and 3 is the orbit achieved by the OTV: APO 3 reaches full GEO orbit, while APO 2 requires the spacecraft have an apogee stage.

APOs 5 to 7 are the space-based OTV versions of APOs 2 to 4 and would involve use of the Space Station. APO 8 is enhanced checkout of the satellite, such as antenna pattern testing, and is to be differentiated from health checks which would be performed at some level during each APO.

2.1 Emergency Retrieval

Emergency retrieval is the most realizable APO and is being used today in limited form from the Shuttle. Insurance underwriters can be expected to require emergency retrieval provisions a standard feature on communications satellites. At present, the faulty satellite usually must wait until a future Shuttle flight for repair or retrieval, and often suffers thermal injury. Short-notice availability of a space-based Orbital Maneuvering Vehicle (OMV) that can dock with a generic satellite would be required.

If a satellite is launched with the OTV, the OTV must wait until the satellite is deployed and operational. If a major failure occurs, the satellite could be retrieved and returned for repair. However, this option requires that additional mass be carried in the form of extra OTV fuel to enable possible return of the satellite and grappling fixtures on the multiple payload carrier.

The non-functional satellite being returned from GEO must be able to withstand the OTV atmospheric aerobraking forces. Although the satellite could not be designed for every contingency, certain safety devices could be implemented to facilitate repair at the Shuttle or Space Station and relaunch without return to Earth.

2.1.1 Scenarios

There are three scenarios for emergency retrieval corresponding to repair at the shuttle, at the Space Station, and on an OTV launch.

Retrieval by Shuttle

1. Satellite is deployed from Shuttle bay and fails to activate.
2. Shuttle approaches within safe distance of satellite.
3. MMU (manned maneuvering unit) or RMS/EVA activity to dock satellite.
    - Attach docking device.
    - Despin satellite if required.
4. Satellite is brought back to Shuttle and grappled with RMS.
5. Satellite may be repaired via extra-vehicular activity (EVA) and ground-originated instructions.
6. If repair is satisfactory, relaunch satellite.
7. If repair is not satisfactory, use safety features designed on satellite to make it comply with Shuttle safety regulations.
8. Return satellite to Earth via Shuttle.
9. Repair satellite and relaunch.

Retrieval at Space Station

1. Satellite is deployed from Shuttle bay and fails to activate.
2. OMV is released from Space Station (SS) and rendezvous with failed satellite.
3. OMV grapples satellite with remote arm or RMS.

4. Satellite is brought back to SS. Slow OMV spin for thermal control.
5. Rendezvous with SS, use MRMS to take OMV and satellite to storage.
6. Undock OMV and satellite, store satellite until servicing.
7. Place OMV back in its storage hanger.
8. Repair satellite via EVA with ground link to satellite experts.
9. If repair not possible, make safety precautions and return to ground on next available Shuttle.
10. If repair is successful, use OMV to place satellite in new orbit away from SS, relaunch.

Retrieval on OTV Launch

1. Satellite is deployed from OTV per OTV APO (2,3,5 or 6).
2. OTV deploys other satellites but does not de-orbit.
3. Satellite begins deployments while being monitored by ground facilities.
4. Satellite continues until on-orbit capability is achieved.
5. If satellite fails during deployment, contingencies are attempted or option to retrieve with OTV is chosen.
6. OTV closes in on satellite in low thrust mode.
7. Redocking of satellite by OTV.
8. OTV returns to LEO and servicing occurs with Space Station or Shuttle.

2.1.2 Requirements on Satellite

- Standard configuration for attachment of RMS grappling fixture.
- Safety features to remotely inhibit all satellite propulsion and pyrotechnic devices.
- Tank purging capability through controlled firing of thrusters or advanced methods.
- Accurate, detailed documentation of satellite available for emergency use.
- Grappling fixture in accessible location if OMV retrieval is required.

2.1.3 Requirements on Shuttle, Space Station and OTV

Requirements on Shuttle

- Retrieval equipment flown on launch.
- Crew prepared for emergency retrieval.

Requirements on Space Station

- OMV available at Space Station for emergency use.
- OMV grappling capability.
- Dedicated servicing equipment at Space Station (servicing bay).
- Storage facilities at SS to provide thermal control.
- Standard power supply for battery charging.

Requirements on OTV

- Orbit holding capability.
- Remote docking capability.
- Additional fuel allocated for return of a satellite.

2.2 Ground-Based OTV Launch to Geostationary Transfer Orbit

The Ground-Based Orbital Transfer Vehicle (GB-OTV) can substitute for the business-as-usual perigee or integral stages used to place most communications satellites into an elliptical geostationary transfer orbit. This would require little change in satellite design and minimize implementation costs. Commercial perigee stages or alternate launch vehicles such as the Ariane would be major cost competitors, but could also serve as reliable back-up systems.

The OTV should simultaneously launch several satellites in order to be cost effective. This requires a reusable Multiple Payload Carrier (MPC), which could be a simple truss-like structure with variable lengths to connect the payloads.

Note that this APO is a launch to geostationary transfer orbit only. This would be more beneficial for a satellite whose launch cost is determined by length, and therefore enabling the fuel mass required for the apogee maneuver to be transported without cost. (An example would be a spinner satellite design with surface area and hence volume determined by power requirements.)

2.2.1 Scenario

1. Satellites and GB-OTV in Shuttle bay, launch to LEO orbit.
2. Deploy GB-OTV plus MPC, (assemble if required).
3. Affix payloads to MPC in predefined configuration.
4. Attach deployable thermal shrouds if required.
5. Release OTV, launch to geosynchronous transfer orbit.
6. If spinning of OTV is required, must despin in GEO transfer orbit.
7. Deploy satellite from MPC.
8. Turn on S/C systems, begin pre-orbit transfer operations.
9. Confirm OTV - S/C distance, begin controlled apogee burn to GEO.
10. Begin satellite on-orbit operation.

2.2.2 Requirements on Satellite

- OTV and back-up launch system attachment compatibility.
- Standard hardpoints for satellite handling during OTV connection.
- Thermal requirements/shroud design for OTV launch.
- Automatic activation of satellite systems upon detachment from OTV.
- Thermal and power data telemetered to ground.

2.2.3 Requirements on Shuttle and OTV

- Multiple payload carrier, capable of supporting several satellites of different masses for the same launch without loss of efficiency.
- Sufficient space on Shuttle with GB-OTV for efficiently packaged satellites (mass vs. length) that optimize OTV use.
- Slow spin capability for OTV to allow satellite thermal control.
- Data communications contact through MPC to satellites if telemetered data cannot be sent by several satellites on OTV.

2.3 Ground-Based OTV Launch to Geosynchronous Orbit

The ground-based orbital transfer vehicle can be used to place satellites into circular geosynchronous orbits. For many types of satellite designs, the elimination of the large amount of fuel and propulsion system required to perform the apogee maneuver can lead to a simpler and more compact design. This, however, requires major redesign of the satellite bus and additional implementation cost. Satellite designs that are driven by other factors, such as the surface area available for solar arrays on a spinner, may not benefit from this APO.

No commercial system yet exists that can launch an unintegrated satellite into geosynchronous orbit in a low thrust mode. Several types of systems have been studied but none have been implemented to date. It is imperative to have such systems developed and tested before a satellite design would incorporate the use of the OTV for this APO.

2.3.1 Scenario

Same as scenario in paragraph 2.2.1 for GB-OTV launch to GEO transfer orbit, except that OTV releases and activates satellite in circular GEO orbit.

2.3.2 Requirements on Satellite

- Same as OTV launch to GEO transfer orbit (paragraph 2.2.2), plus
- No apogee motor needed: large decrease in fuel results in smaller fuel tanks and possible change to less efficient fuel requiring less hardware
- Possible redesign of satellite bus to be more space efficient
- Fewer control and deployment modes: one set of on-orbit deployment modes, no transfer orbit modes needed.
- Operates with OTV or commercial external transfer system.

2.3.3 Requirements on Shuttle and OTV

- Same requirements as OTV launch to GEO transfer orbit (paragraph 2.2.3).
- The Shuttle must maintain its orbit for a longer time until the GB-OTV can return from the full GEO launch.

2.4 Deployment of Appendages at Shuttle

The externally-assisted deployment of appendages in low earth orbit would create a major change in the business-as-usual approach to satellite design and launching. New designs for appendages could be implemented that are not dependent upon automatic deployment mechanisms. However, the deployed satellite would have to be able to withstand the 0.1 G force of the OTV or other low thrust launch vehicle. Reliability will be increased through simplification of automatic procedures and testing of the on-orbit configuration. Some cost savings can be gained through the elimination of zero-gravity simulations of complicated deployment schemes.

2.4.1 Scenario

1. Deploy GB-OTV from Shuttle.
2. Remove satellite from cradle with RMS.
3. Affix satellite to raised work station or lock arm to hold satellite in usable orientation within EVA reach.
4. EVA assisted deployment of antennas, solar arrays, other appendages.
5. Test on-orbit configuration as per checkout APO (subsection 2.8).
6. Launch satellite with low thrust launch vehicle such as OTV (2.3).

2.4.2 Requirements on Satellite

- Standard hardpoint for RMS handling.
- Separate connection interface for workstation.
- Devices for deployment of appendages or methods of safe deployment via EVA.
- Deployed appendages must withstand low thrust (0.1 G) of OTV.
- For operation before 1997, a back-up mode required for deployments.
- Satellite appendages are limited in size by the MPC and other satellites being simultaneously launched.

2.4.3 Requirements on Shuttle and OTV

- Trained satellite handlers on Shuttle flight.
- Low-thrust mode (0.1 G) for OTV.
- Raised workstation accessible for EVA.

2.5 Space-Based OTV Launch to Geostationary Transfer Orbit

The use of the Space-Based (SB) OTV which is based at the Space Station has the advantage of not having to carry the GB-OTV up in the Shuttle for each launch. (The GB-OTV will not be left in LEO between missions.)

2.5.1 Scenario

1. Satellites are launched via Shuttle direct to Space Station. (Optional use of OMV to move satellites from nominal Shuttle orbit to Space Station, or unmanned cargo transport to Space Station via expendable launch vehicle (ELV).
2. RMS and MRMS used to transfer satellites to SB-OTV.
3. Attach satellite to MPC on SB-OTV, ready to launch.
4. Dock OMV to OTV.
5. Use OMV to move OTV away from Space Station.
6. Launch OTV to GEO transfer orbit.
7. Release each satellite and launch to full GEO orbit.
8. Return OTV to Space Station.

2.5.2 Requirements on Satellite

- OTV and back-up launch system attachment compatibility.
- Hardpoints for satellite handling during OTV connection.
- Thermal requirements/shroud design for OTV launch.
- Automatic activation of satellite systems upon detachment from OTV.

2.5.3 Requirements on Space Station

- Efficient scheduling of OTV with Shuttle to avoid satellite storage.
- Safe, quick transfer of satellites from Shuttle bay to OTV.
- Quick connect docking procedure.
- Multiple payload carrier, capable of supporting several satellites of different masses for the same launch without loss of efficiency.
- Slow spin capability for OTV to allow satellite thermal control.

2.6 Space-Based OTV Launch to Geosynchronous Orbit

The Space Station and SB-OTV can be used for launch to full geosynchronous orbit. The scenario would be the same as paragraph 2.5.1, except that the launch is into full geosynchronous orbit. The requirements on the satellite are the same as paragraph 2.5.2, and the requirements on the Space Station are the same as paragraph 2.5.3.

More details of OTV performance is given in Subsection VII-2.3.

2.7 Deployment of Appendages at Space Station

The deployment of appendages at the Space Station and the subsequent testing before OTV launch has advantages over a Shuttle based operation (Subsection 2.4) where operation time is limited. More elaborate deployments can be performed at the Space Station, and concentrated testing of the on-orbit configuration could add significant value to the operational life of the satellite. This APO requires that additional equipment and a dedicated servicing and testing bay for satellites be placed on the Space Station.

2.7.1 Scenario

1. Satellites in Shuttle bay transported directly to Space Station.

2. RMS and MRMS used to transfer satellites to Space Station storage bay and servicing/deployment area.

3. Position satellite in serving area.

4. EVA assisted deployment of appendages.

5. Test on-orbit configuration (Checkout APO, subsection 2.8).

6. SB-OTV launch scenario (paragraph 2.5.1) with low (0.1 G) thrust.

2.7.2 Requirements on Satellite

- Deployment requirements same as at Shuttle (paragraph 2.4.2).

- More advanced testing capability required.

2.7.3 Requirements on Space Station

- Dedicated servicing/deployment area with adequate area to deploy booms, arrays, etc. without obstructing other operations.

- This may require external facilities, electrical power, and communication systems if there is not enough space in the service bay.

- Storage facilities providing thermal control for undeployed satellites or satellites requiring active thermal control prior to OTV launch.

- Battery charging facilities for satellites.

- Efficient scheduling of OTV-Shuttle to avoid excessive satellite storage.

- Trained EVA satellite handlers on Space Station crew.

- Low thrust (0.1 G), efficient OTV.

2.8 Checkout at Space Station

Health checks via a standard data port are made on the satellite before launch and deployment. It may be desirable to have a more thorough checkout of satellite systems, especially if the satellite can be deployed into its on-orbit configuration at the Space Station (or Shuttle).

New tests could include power levels, accurate center of mass properties, and detailed communication systems tests. Basic tests such as power levels could be conducted from the Shuttle, but more complicated tests such as antenna patterns that could enhance the reliability of full on-orbit operation would require extra equipment more appropriately placed on the Space Station.

Requirements for this APO may be driven by the insurance underwriters and trends in satellite failures. The checkout APO will become more cost effective when combined with other APOs.

2.8.1 Scenario

1. Satellite is brought to Station and stored.

2. Routine health checks are carried out while at Space Station. (Other APOs would also incorporate routine health checks.)

3. After launch configuration is completed (possible exception of fueling), satellite is placed in servicing bay or dedicated testing facility.

4. Tests are performed. If anomalies are found, attempt repair and/or transport to ground.

5. Far field antenna testing may require use of an OMV to transport satellite to adequate test range and control pointing during tests.

6. Antenna test equipment at SS is used to test patterns.

7. Satellite on OMV is returned to Space Station.

8. Launch satellite on OTV or alternate launch system.

2.8.2 Requirements on Satellite

- Standard hardpoints to allow satellite handling.
- Equipment to allow communications with systems being tested.
- Added abilities to facilitate testing such on/off control of single transponder.
- Standard data port.

2.8.3 Requirements on Space Station

- Servicing/testing bay facility with power supply, data communications port, thermal control.
- Storage facility with thermal control.
- Standard testing equipment and small mobile equipment for servicing.
- Antenna testing system with power level and pointing capability.

2.9 Fueling at Space Station

The fueling of mono- or bi-propellants at the Space Station will allow the optimization of satellite tank designs in order to achieve minimum mass and volume. Additional hardware such as fuel pressure and temperature meters and shut-off valves will be required on the satellite for safety. The fuel could be carried in bulk by a transport vehicle to the vicinity of the Space Station or else scavenged from the Shuttle fuel tanks.

Safety concerns may lead to fueling becoming a requirement for Space Station operations. Possible concerns are (1) to provide adequate safety during EVA handling, assembly or testing, and (2) to avoid the necessity for purging the tanks if faults are found in a satellite during testing and return to a ground-based facility is required.

The advantage that fueling may offer is directly related to the amount of fuel that a satellite requires. The use of the OTV, especially when used to launch satellites into geosynchronous orbit, will decrease the advantage of fueling. Systems designed to use liquid fuels for integrated launch stages will see increased advantage of low cost Space Station fueling.

2.9.1 Scenario

1. Satellites in Shuttle, launch to Space Station.
2. RMS and MRMS used to move satellites to storage facility or fueling depot.
3. Affix satellite to fueling ports.
4. Fuel satellite with propellant and pressurant.
5. Disconnect satellite.
6. Transfer to OTV if self-propelled or to OMV for maneuvering away from SS.

2.9.2 Requirements on Satellite

- Standard hardpoints to allow satellite handling.
- Standard quick disconnect fueling ports.
- Fueling meters for internal pressure, temperature with communications port to allow constant interface during fueling and for health checks.
- Dust covers and shielding to prevent damage or contamination of ports.

2.9.3 Requirements on Space Station

- Propellant/pressurant storage and fueling facility.
- Availability of low cost fuel; i.e. scavenged fuel with no charge for mass transport to LEO
- Standard fueling ports that provide safe, quick connect/disconnect.
- Satellite storage facilities to provide thermal and contamination protection prior to OTV connection.

- Standard communications port to allow fueling interface and health checks.
- Battery charging facilities to allow maximum satellite charge on launch.
- OTV requirements per paragraph 2.5.3.

2.10 Assembly of Satellite at Space Station

Assembly of satellites at the Space Station may offer advantages, but will require satellite redesign. Fewer structural restraints such as size, shape, and position of appendages will allow mission-specialized designs with better performance. The satellite design could make more efficient use of Shuttle space, with appendages able to be stored separately from the satellite.

2.10.1 Scenario

1. Satellite and appendage modules in Shuttle, transport to Space Station.
2. RMS and MRMS transfer parts to SS storage area with thermal control.
3. Transfer bus to servicing/assembly bay, affix communications and electrical ports, perform bus health check.
4. Use MRMS to bring modules and appendages to assembly site, affix via EVA or teleoperator, perform health check test.
5. Continue assembly until complete.
6. Perform checkout after assembly.
7. Launch with low-thrust OTV as per scenario in paragraph 2.5.1.

2.10.2 Requirements on Satellite

- Communications/data, and battery charging/power ports.
- Standard hard points or hand holds for bus and all parts to avoid damage during unpacking and assembly. For use in handling by RMS or EVA.
- Shielding, dust covers for ports and fragile equipment to prevent damage during docking or assembly, and to prevent contamination.
- All loose and protruding equipment must be non-sharp to avoid damage of EVA suits or other Space Station equipment.
- All tools required for assembly should be standardized.
- Simple assembly/construction features, yet accurate alignment is required.
- Size and mass limited by Space Station.
- Efficient packaging of satellite equipment.
- Full assembly sequence of events prior to launch, subject to NASA approval.
- Fully assembled and deployed satellite must withstand standard low thrust.

2.10.3 Requirements on Space Station

- Communication/data, and battery charging/power ports at assembly site.
- Dedicated area for construction/assembly that will define maximum size and mass as well as other constraints (forces, safety, etc.).
- Storage area for unassembled parts (passive thermal and physical protection).
- Manipulator system (MRMS) to aid in assembly.
- Cherry picker or mobile foot restraint (MFR) arms to access satellite parts not accessible from standard work area.
- Ability to pre-flight test communications systems (could use OMV to separate satellite required distance from Space Station).
- Efficient method of remembering/communicating (heads-up display).
- Low thrust (0.05 to 0.1 G) OTV for efficient single satellite (1500 kg) transfer to GEO.

2.11 Servicing for GEO Satellites

Before satellites can be serviced in GEO, years of success in LEO and testing in GEO will be required. This APO defines GEO servicing as retrieval and repair/refurbishment of a satellite in geostationary orbit. This can be as simple as remote retrieval and return to the Space Station or Shuttle, or as complicated and refined as robotic repair/replacement of modules and on-orbit refueling. For this APO, two specific scenarios will be addressed: (1) retrieval and return to the Space Station will be studied as an early type of servicing; and (2) replacing modules in a satellite designed for servicing with a telepresence system.

The retrieval scenario requires added OTV capabilities as briefly addressed under emergency retrieval (paragraph 2.1.3). The design changes on the satellite to be retrieved become the deciding factor. Assuming the aerobraking capability of the OTV is to be used, the satellite appendages extending beyond the aerobraking envelope must be automatically stowed. In addition, all unstowed appendages must withstand the transport forces.

The replacement scenario requires several technology developments on both the satellite and servicing system. Telepresence is defined as an operation that is performed robotically under the control of a remotely manned system whose inputs are entirely artificial sensors such as video or force sensors. For GEO servicing, this requires accommodating several tenth-of-second time delays, and achievement of modularized satellite designs and remote docking/servicing equipment.

2.11.1 Scenarios

Retrieval from GEO to LEO

1. OTV with retrieval capabilities or OMV is launched into GEO orbit.
2. S/C automatically stows appendages and despins.
3. Prepare for docking, propulsion system shutdown.
4. OTV rendezvous with satellite.
5. Docking with OTV completed.
6. Return to Space Station or Shuttle.
7. Service satellite as in emergency retrieval APO (subsection 2.1.1).
8. Relaunch satellite.

Servicing in GEO

1. Launch OTV with robotic servicing unit which is an OMV with smart servicer (some autonomous operation capability, not necessarily artifical intelligence) and Orbital Spacecraft Consumables Resupply System (OSCRS).
2. Shutdown satellite propulsion and control systems.
3. Rendezvous and dock with servicer.
4. Fuel, exchange modules, attempt servicing repair on non-modularized equipment.
5. Undock and separate from satellite.
6. Test new on-orbit operation.
7. Re-service if errors still exist, make retrieval decision.
8. Return servicer to storage bay in GEO or return via OTV.

2.11.2 Requirements on Satellite

Retrieval from GEO to LEO

- Appendages automatically stowable or within OTV aerobraking envelope.
- All unstowed appendages able to withstand forces of aerobraking and OTV de-orbiting accelerations.
- Propulsion and control system shutdown capability.
- Standard grappling fixture for retrievability.

Servicing in GEO

- Standard grappling fixture.
- Propulsion and control system shutdown capability.
- Modularized components that may fail or become obsolete.
- Detailed satellite documentation.
- Refueling capability if desired (Subsection 2.1.9).

2.11.3 Requirements on OTV and Space Station – Retrieval to LEO

- Docking capability via video/laser system.
- Standard grappling feature with grapple fixture.
- Envelope characteristics; controllability with excess mass during aerobraking.
- Requirements as per emergency retrieval APO (paragraph 2.1.3).

2.11.4 Requirements on Servicer Used in GEO

- Standard grappling and docking features.
- Telepresence/robotic capability.
- Modular replacement capability.
- Mobilized fueling capability (OSCRS).
- Docking and servicing provides safe environment for satellite (plume impingements, arm movement, etc.).
- Ground-based control via telepresence system.
- Low cost operations (satellite value versus cost and value gained).

3 Impact on Satellite Design

The APOs discussed in the previous subsection each require that modifications be made to the baseline satellite design.

Tables VI-1 and VI-2 give the impact of the APOs on the spinner and 3-axis satellite designs respectively. These tables show how the APOs change the mass of the different satellite subsystems. The communications payload, power, and thermal subsystems are not tabulated as they are not affected by the APOs.

The integration and test column indicates how much the cost of integration changes. It is proportional to mass change unless the complexity of the task changes. Satellite integration and test costs are increased 5% for APOs using the Space Station. For example, EVA and IVA (external and internal vehicular activity) may be tested in a zero gravity tank before use in space.

3.1 Retrieval APOs

The primary change to the satellite design for retrieval is the implementation of a grappling fixture.

For a Shuttle-based retrieval, the implementation is designed to have the minimum impact on the satellite. Fixtures are added to the satellite to allow manual attachment via EVA of the standard grappling fixture (SGF) with grappling bars and trunnion pin attachment devices. The standard grappling fixture is required to allow handling by the Shuttle remote manipulator system (RMS) or mobile RMS (MRMS) at the Space Station.

For a Space Station retrieval, the satellite design must contain the SGF in a location accessible to the OMV which is used to transport the satellite from its launch orbit to the Space Station. Additional structural mass is required to support the SGF.

A GEO retrieval uses the SGF for retrieval by the OMV and requires additional structural mass for an OTV docking interface that can withstand the forces experienced during aerobraking with the OTV.

Additional changes to the baseline satellite would be to allow re-safing of the propulsion sys-

	Mass of Subsystem (kg)				Total Mass (kg)	Int. & Test (%)
	Attitude Control	Propulsion	Structure	TT&C		
Baseline Satellite	40	113	227	37	1,059	–

APOs at Shuttle	Difference from Baseline (kg)					Int. & Test
	Attitude	Propulsion	Structure	TT&C	Total	
LEO Retrieval	–	–	+4.1	–	+4.1	+.1
GB-OTV to GTO	+5.6	+5.3	+23.4	–	+34.3	+2.2

APOs at Station	Difference from Baseline (kg)					Int. & Test
	Attitude	Propulsion	Structure	TT&C	Total	
LEO Retrieval	–	–	+28.0	–	+28.0	+.9
SB-OTV to GTO	+5.6	+5.3	+28.0	–	+38.9	+12.0
Checkout	+3.0	–	+28.0	+3.0	+34.0	+1.0
Fueling	–	+2.0	+18.0	–	+20.0	+1.2
GEO Retrieval	–	–	+33.0	–	+33.0	+.2
Combination	+8.6	+7.3	+23.0	+3.0	+41.9	+14.0

Table VI–1: Impact of APOs on Spinner Satellite Design

	Mass of Subsystem (kg)				Total Mass (kg)	Int. & Test (%)
	Attitude Control	Propulsion	Structure	TT&C		
Baseline Satellite	48	114	176	35	1,176	–

APOs at Shuttle	Difference from Baseline (kg)					Int. & Test
	Attitude	Propulsion	Structure	TT&C	Total	
LEO Retrieval	–	–	+4.1	–	+4.1	+.2
GB-OTV to GEO	–	-60.0	+13.4	–	-46.6	-6.0
Deploy appendages	–	–	–	–	–	–
Combination	–	-60.0	+13.4	–	-46.6	-6.0

APOs at Station	Difference from Baseline (kg)					Int. & Test
	Attitude	Propulsion	Structure	TT&C	Total	
LEO Retrieval	–	–	+28.0	–	+28.0	+1.0
SB-OTV to GEO	–	-60.0	+18.0	–	-42.0	-1.1
Deploy appendages	–	–	+28.0	–	+28.0	+6.1
Checkout	+3.0	–	+28.0	+3.0	+34.0	+11.6
Fueling	–	+5.0	+23.0	–	+28.0	+12.3
GEO Retrieval	–	–	+33.0	–	+33.0	+6.3
Combination	+3.0	-55.0	+18.0	+3.0	-31.0	+7.1

Table VI–2: Impact of APOs on 3-Axis Satellite Design tem. These changes have been studied and have relatively little cost impact on the satellite.

3.2 OTV APOs

3.2.1 Spinner Design

The design of a spin-stabilized satellite is such that the power requirements of the payload determine the size of the satellite, or conversely the satellite size limits the power available for the payload. The spin-stabilized satellites are limited in power based on the solar array area on the surface of the satellite. Additional area is sometimes created by deploying an external shroud of solar cells to effectively double the length of the satellite. The area inside the new length is not used because it is not needed.

If the OTV were used, the propellant tanks that exist inside the main cylindrical body would not be needed. However, the cost of a Shuttle launch for the satellite would not decrease because launch costs are determined by length and not mass for this satellite design. Therefore, it is more economical to include the propellant and apogee motor (no increase in launch costs) and use the OTV in place of the conventional perigee motor for transport to geosynchronous transfer orbit (GTO). It is uneconomical to use the OTV to transfer a spinner satellite to full geosynchronous orbit.

Use of an OTV for transfer to GTO requires that the satellite be capable of spinning up by itself. The satellite must also be capable of obtaining a 3-axis reference after separation from the OTV. The equipment required for these operations are non-radial spin thrusters or rockets, an additional axis sensor (rate gyro coupled with earth and sun sensor or other system), and onboard software to perform the new maneuvers.

Control of the satellite thermal environment is achieved by spinning the satellite at a relatively high rate. The OTV is not capable of spinning at the required rate and it is necessary to include a thermal shroud for each satellite during OTV launch. Even if the OTV provides a slow spin, the thermal protection would be required for transfer operations from Station to OTV.

Use of the OTV requires a standard grappling fixture to allow RMS handling and an OTV/MPC (multiple payload carrier) interface. Handling at the Space Station may require additional hand holds and fittings.

Integration and test increases due to the combined effects of the additional mass and the additional ground testing required to simulate operations at the Space Station.

3.2.2 3-Axis Design

A 3-axis design can benefit by using an OTV to replace the current perigee and apogee stages. This allows the satellite size to shrink slightly by removing the apogee motor and bipropellant tanks. The bipropellant system would be replaced by a less complicated hydrazine system for station keeping and altitude control. The central structure mass is reduced since it is no longer required to support the large propellant mass at launch.

A standard grappling fixture is added to allow RMS handling while additional handling devices allow EVA handling at the Space Station.

Integration and test decreases because of the significant decrease in satellite mass.

3.3 Deploy Appendage APOs

Deployment or assembly of appendages at the Shuttle or Space Station requires that the satellite be launched into geosynchronous orbit by a low thrust vehicle. An SGF must be added to allow handling outside of the Shuttle bay or Station storage area. There is no appreciable mass change to the design as the handling fixtures mass offsets the mass lost due to removal of the automatic deployment and partial deployment devices.

Use of this APO with spinning satellites is not desirable. The spin-up procedure requires simultaneous stabilization of the equipment platform to avoid large angular acceleration forces on the appendages. This requires active acceleration sensors that are coupled with the platform stabilization device, creating a complicated control loop which decreases the reliability of the single failure point in the despun platform configuration. The advantage in deployment reliability is offset by the spin-up problems of the spin-stabilized satellite.

For the 3-axis satellite design, there is a definite advantage for larger appendages which can be packaged separately for Shuttle transport and then attached at the Station.

3.4 Checkout APOs

Checkout capability at the Space Station would require additional on-board failure detection. This feature can be approximated by added capability in the attitude control and TT&C subsystems. A satellite using antenna pattern testing would require deployment of appendages as previously discussed. The satellite being tested at the Space Station would require the standardized power and communications ports and handling capability which includes the addition of a SGF. These last changes are required of all satellites utilizing the Space Station.

3.5 Fueling APOs

The capability to fuel a satellite at the Space Station creates two major impacts to the baseline satellite design.

1. The fuel tanks must be modified in order to allow on-orbit fueling. Current tanks are designed to withstand the on-orbit pressures. Standardized fueling ports would be required. Bipropellant systems would require either two ports or a common port with line switching capability.

2. Removal of fuel on launch reduces the strength requirements on the satellite central support system and allows a savings in structural mass when lower thrust upper stages are used. Use at the Space Station will require handling capability and standardized communication and power interfaces.

3.6 Assembly APOs

Implementation of assembly of the satellite may take many forms. Simple assembly of appendages may be used if future appendages do not fit in the Shuttle or expendable launch vehicle envelopes. If a satellite is fully modular, it may be assembled and easily serviced by replacing failed or old equipment.

The impact on the design can range from alignment guides and manual locks for appendages to precise electrical connectors and mechanical housings for each subsystem or part of a subsystem. The mass impacts for assembly are also variable. Analysis of various modular designs show that up to a 20% increase can be required. The integration and testing of a satellite to be assembled would show a significant increase due the greater amount of equipment.

Contemporary communication satellite sizes do not appear to benefit from assembly in the sense that a large platform would. In addition, spin-stabilized designs do not readily show assembly capability or the potential for simple equipment replacement.

3.7 Servicing APOs

Satellite servicing in geosynchronous orbit requires that the satellite design be modular is discussed in the previous paragraph. In addition, the satellite may need to be designed for autonomous changeout of modules for designs before the year 2000. This may require additional specialized fittings and ports that must be tested by changeout simulations prior to launch. Servicing may also require fueling impacts as discussed in Subsection VI-3.5.

4 Discussion

4.1 APO Timelines

Table VI-3 gives possible timelines of the first communication industry implementation for each APO. The timelines are based on the following three assumptions:

- OTV and Space Station timelines as given in Table VI-3;
- Reliable backup systems are available; and
- Successful APO proof-of-concept tests have been carried out.

	APO	Date
1.	Emergency retrieval	
	– at Shuttle	1985
	– at Space Station	1994
	– at OTV	1995
2.	GB-OTV to GTO	1995
3.	GB-OTV to GEO	1996
4.	Deploy appendages	
	– at Shuttle	1997
5.	SB-OTV to GTO	1998
6.	SB-OTV to GEO	1998
7.	Deploy appendages	
	– at Space Station	1998
8.	Checkout	
	– at Space Station	1998
9.	Fueling	
	– at Space Station	1998
10.	Assembly	
	– at Space Station	1998
11.	Servicing for GEO	
	– Transport to LEO	1999
	– Servicing in GEO	2000

Table VI–3: Timelines for APOs

It is expected that the communications industry will take advantage of economically or technically advantageous APOs within two years after successful test. The more advantageous the APO, the sooner it will be implemented. Without backup systems such as alternate launch vehicles, the satellite design would be postponed until proof of reliability was available. Satellite design and fabrication will continue to require 3 to 5 years from start to launch. Thus an APO might not be implemented for 6 years after successful testing.

4.2 Combinations of APOs

Several APOs can be combined to build a more efficient scenario. Some APOs such as checkout do not appear to be efficient as a stand-alone option, but when combined with others such as deployment or assembly become quite attractive as added capability. It is expected that the Shuttle-based APOs (2,3,4) will combine with each other (deployment and launch with GB-OTV) but will not interact with the Space Station based APOs (5-10).

The Space Station based APOs allow for a wider variation of capabilities that may be used together for technological and economic advantage over the business-as-usual operations. Some APOs will be assumed to occur for most satellites, others may eventually be required for safety reasons, while still others may see only limited use in the foreseeable future. Some level of checkout will be performed on every satellite, if only for the business-as-usual thermal and health checks. Advanced forms of checkout such as antenna pattern measurement will need detailed analysis to ascertain the reliability gained versus the cost to perform the checkouts.

Fueling will need to be cost effective before it is implemented, although Space Station safety requirements may make it necessary for some types of operations such as assembly or storage. Finally, more advanced APOs such as assembly and GEO servicing may be included, although these types of operations are presently considered high risk, and therefore will probably not be initially used by the commercial communications industry.

Section VII
ECONOMICS OF APOs

1 Introduction

This section presents the Task 3B evaluation of the APO's economics. Results are presented for the spinner and 3-axis satellite APOs as described in Section VI. The baseline satellite designs are the spin-stabilized Ku-band and 3-axis hybrid cases described respectively in Subsections IV-3.1 and IV-3.3. The case of the OTV launch of the large satellite design described in Subsection IV-4 is also presented.

The methodology used to determine the APO value is described first in Subsection 2. Subsections 3, 4, and 5 discuss respectively the economic performance of the APOs for the spin-stabilized, 3-axis, and large satellite designs.

2 Methodology

2.1 APO Values

The APO value is defined as the "fee" NASA could charge for the APO that would result in the same economic performance as for the business-as-usual scenario. An additional incentive of 1% increase in DTRR return, which is equivalent to a capital expense of approximately \$12 M, is judged to be necessary as an incentive for potential users but has not been subtracted from the APO fee.

The following procedure is used to determine the APO values:

- The baseline satellite design is modified to reflect the APO requirements. The satellite payload is not altered.
- The new satellite costs are determined via the Price H cost model.
- The Financial Model is run with inputs appropriate to the APO:
  - Satellite cost from Price H;
  - Shuttle launch costs based on mass and volume of satellite and upper stage;
  - Perigee stage costs;
  - Launch support costs;
  - Mission operations costs; and
  - Launch insurance costs.
  - The "fee" for the APO is not initially included.
- The Model output is compared with baseline results to determine the value of the APO.
- The Model is iterated with the APO "fee" as input until the baseline rate-of-return (DTRR) is equaled. The result is the APO value. (Note that the APO value is subject to launch insurance.)

2.2 Launch Insurance

A major item for potential cost savings from implementation of APOs is launch insurance.

2.2.1 Launch Insurance Rates in 1995

The baseline 20% rate predicted for launch insurance in 1995 is derived from the 16% average loss rate over the last decade plus 4% overhead. The actual future rate will be based on the insurance underwriters past experience. Since the launch insurance cost is itself insured, the baseline 20% rate is effectively 25% of all other costs except the insurance.

Failure Category	Failures Number	Percent
Initial stage	5	16
Perigee stage	11	34
Apogee motor	10	31
Spacecraft	3	9
Satellite	3	9

Table VII–1: Incidents of Satellite Failure

A variation of the rate by 5% changes the cost of insurance by $5 M and the DTRR return by 0.5% (Subsection III-5.2).

2.2.2 Incidents of Satellite Failure

Table VII-1 categorizes 32 incidents of satellite failure from 1963 through 1985: 7 in the 1960's, 9 in the 1970's, and 16 in the 1980's. The primary cause of satellite losses and the claims paid by underwriters has been launch vehicle malfunctions [*Space*, Vol. II, No. 11]. Of the 30 civilian communications satellite malfunctions up through 1985, 24 have been related to launch systems.

The distinction between spacecraft and satellite in Table VII-1 is that the spacecraft becomes a satellite the after initial operational capability is achieved; i.e. on orbit acceptance testing has been successfully completed.

2.2.3 Influence of APOs on Rates

Table VII-2 gives the projected insurance rate changes in points for the individual APOs. A one point decrease in insurance gives a rate of 19% versus the baseline 20%.

The APO with the largest potential effect on launch insurance is the use of the OTV. As shown in Table VII-1, 34% of historical losses occurred in the perigee stage and 31% in the apogee launch stage. A perfectly reliable OTV to GTO could result in a 5.4% reduction and the OTV to GEO could result in a 10.4% reduction in launch insurance (out of the total 16% loss rate). Since the OTV APOs will introduce new risks (i.e. transfer of satellite from Shuttle to OMV to Station to OTV), it is judged that rates will decrease a somewhat lesser amount as shown in Table VII-2.

APOs at Shuttle	Rate Decrease Points
LEO retrieval	1.0
Deploy appendages	1.0
GB-OTV to GTO	2.0
GB-OTV to GEO	5.0

APOs at Station	Points
Fueling	0.0
LEO retrieval	1.0
Deploy appendages	1.0
Checkout	1.0
GEO retrieval	1.0
SB-OTV to GTO	3.0
SB-OTV to GEO	7.0
Spinner combination	6.0
3-axis combination	9.0

Table VII–2: Influence of APOs on Insurance

The ground-based OTV will act as a test bed for the space-based OTV and will have to undergo launch from Earth. Therefore, it is judged to be somewhat less reliable than the space-based OTV. The other APOs were judged to have the potential to affect rates as shown in Table VII-2.

The fueling APO has no positive impact on insurance rates. Fueling at the Space Station does not directly decrease chance of failure. In fact, the increased complexity of additional valves in the fueling system slightly increases the risk of failure. It is assumed that NASA safety precautions will offset any potential risks associated with fueling. A related issue is that these safety precautions may impose addition paperwork and hardware requirements that increase satellite cost.

A one point decrease in launch insurance rate is shown for the retrieval APOs. The actual value of retrieval depends on the details of the satellite design and risk of failure, and on whether there is a satellite repair facility at the

Space Station. The capability for retrieval may be required as a condition of launch insurance and by international treaty to avoid the proliferation of space junk.

The 3-axis combination APO at the Space Station of deploy appendages, checkout, fueling, OTV launch to GEO, and GEO retrieval is judged to result in a nine point drop in launch insurance. This is less than the simple sum of the individual APO impacts since the act of checkout at the Space Station reduces the risks of failure from all other causes. Likewise the spinner combination APO at the Space Station of checkout, fueling, OTV launch to GTO, and GEO retrieval has a six point drop in launch insurance.

Launch insurance rates for combinations of APOs are unlikely to drop below 10% due to the unknown risks inherent in new space activities. It must be emphasized that insurance rates for APOs will not drop until there has been successful demonstration of the APOs.

2.3 Launch Costs

Launch costs are a significant element in the cost of the baseline satellite and APO value. Launch costs include the following items:

- Fees for use of the Shuttle;
- Cost of refurbishment of the cradle on which the satellite plus upper stage is carried;
- Costs of the perigee and apogee stages (upper stages);
- Fee for use of the OTV (if used);
- Launch support cost (before launch);
- Mission operations costs (from launch to operational satellite).

Space transportation alternatives are discussed in Subsection IV-2.8.

2.3.1 Shuttle to LEO

The Shuttle launch cost is based on mass and volume of satellite and upper stage mounted on a cradle. APOs which reduce satellite mass may not affect Shuttle launch charges if length is the determining factor.

2.3.2 Integral Upper Stage

The integral upper stage or perigee stage alternatives are shown in Table IV-4. The perigee stage is purchased and integrated with the satellite on the ground. The apogee motor is also integrated with the satellite. The combined satellite plus upper stages is placed in a reusable support cradle and transported by Shuttle to LEO.

2.3.3 Orbital Transfer Vehicle

The orbital transfer vehicle (OTV) is planned to be available for 1995 launches as an alternative to the conventional integral upper stage. Two types of OTVs are planned:

- **Ground-based OTV.** The GB-OTV is brought up to LEO by the Shuttle for each use, possibly in the aft cargo carrier (a removable cover on back end of the Shuttle external fuel tank used to give added launch volume). The GB-OTV is a proof-of-concept vehicle independent of the Space Station and is planned to be operational in 1995.
- **Space-based OTV.** The SB-OTV is based in LEO at the Space Station and is planned to be operational in 1998.

The advantage of the SB-OTV is that its mass is already in LEO and Shuttle transportation charges are not incurred. Only the fuel for the SB-OTV must be transported from Earth to LEO, and this can occur at low cost as filler material on Shuttle flights that are not completely full. However, the large capacity of the OTV requires that at least two satellites be simultaneously launched in order to be economical.

2.3.4 Comparison of Launch Costs

Launch cost consists of Shuttle charges and upper stage charges. Table VII-3 gives launch charges for the 1995 spinner and 3-axis satellites with integral and OTV upper stages, for single and dual satellite launches at 1 G.

The 1985 schedule of Shuttle charges is used. OTV charges (in 1985 dollars) are based on current NASA estimates as follows:

Spinner		Cost per satellite		
Perigee Stage	No. Sats.	Shuttle	Upper Stage	Total
Integral	–	29.9	3.1	33.0
SB-OTV	1	21.0	16.2	37.2
SB-OTV	2	21.0	10.3	31.3

3-Axis		Cost per satellite		
Perigee Stage	No. Sats.	Shuttle	Upper Stage	Total
Integral	–	35.4	6.9	42.3
GB-OTV	1	51.5	24.1	75.6
GB-OTV	2	34.3	14.1	48.5
SB-OTV	1	16.1	30.6	46.7
SB-OTV	2	16.1	18.4	34.5

Table VII–3: Launch Cost Comparison

- OTV use fee: \$7.8 M total;
- OTV launch services: \$2.7 M single and \$3.7 M double satellite launch.
- Propellant cost at \$1200/kg for GB-OTV and \$1765/kg for SB-OTV.
- GB-OTV transported on Shuttle for each launch; full cost of transport charged to satellite launch mission; \$2.4 M fee for use of aft cargo carrier (behind external tank).
- 1 G launch; 0.1 G is required if satellite appendages are deployed, and propellant cost is 10% higher.

Propellant cost is the major cost with exact value depending on launch orbit and number of satellites launched. There can be considerable variation in SB-OTV propellant cost depending on whether the full cost of transport to LEO is paid or if some scavenging or dunnage scheme is used to lower costs. A figure of \$1765/kg, which is in the middle of the estimates of \$440/kg to \$2200/kg for scavenging, is our best estimate of OTV fuel cost. Non-scavenged fuel, transported at full cost by the Shuttle to a fueling depot at the Space Station is estimated to cost \$3500/kg.

Launch Thrust (G)	Time in Hours GTO	GEO
.05	17	42
.10	11	36
.15	11	36
2.0	1	12

Table VII–4: OTV Launch Time versus Thrust

2.3.5 Time for OTV Launch

The OTV is planned to have several G thrust and be variable over at least a factor of ten. The deployment of appendages at the Space Station (Subsection VI-2.7) requires use of low thrust (0.05 to 0.1 G).

Table VI-4 gives OTV launch times to GTO and GEO orbits as a function of OTV thrust. The launch times are quantized due to the use of an integer number of perigee maneuvers for greater efficiency. (Three perigee maneuvers are required for .05 G and two for .10 and .15 G launches to GEO. A half orbit wait is required for the 2 G launch to GEO.) These are the minimum times thought possible, and assume that trim burns are not required and that accurate orbit determination can be made in one orbit.

The time for return of the OTV from GEO to the Space Station is still uncertain because of the unknown efficiency of the aerobrake. Several passes through the upper atmosphere are required. The estimate for return time is 15 hours for a high G return plus OMV rendezvous time.

The conclusion is that a low-thrust OTV mission will take a minimum of 2 to 3 days..

2.3.6 OTV Performance

The major cost for use of the OTV is its fuel. Depending on payload mass, number of perigee maneuvers, and OTV thrust, the ratio of propellant mass to payload mass ranges from two to four for transfer from LEO to GEO. Estimates for fuel cost (1995) in LEO are \$1800/kg with extremes of \$700/kg and \$3500/kg.

The following points about OTV fuel use can be made:

- For a given payload, use of higher OTV thrust results in less propellant consumption.
- The OTV is more efficient when fully loaded. This means simultaneous launch of multiple satellites using a multiple payload carrier.
- OTV aerobraking for return to LEO is very efficient and can save 5,000 kg of fuel on a 4,000 kg payload launch to GEO.

OTV costs are discussed further in Subsection VII-2.3.

3 Spinner APO Values

The values of APOs for the spin-stabilized satellite are summarized in Table VII-5 and discussed in turn. The spin-stabilized satellite design was presented in Subsection IV-3.1. The discussion of spinner APO value is divided into two parts: APOs at the Shuttle and APOs at the Space Station.

3.1 Spinner APOs at Shuttle

There are two APOs that are envisioned for the spin-stabilized satellite at the Shuttle: (1) retrieval and (2) use of the GB-OTV for launch to geostationary transfer orbit (GTO).

3.1.1 LEO Retrieval Capability

The capability to support a future retrieval mission impacts the baseline satellite design. This impact is described here and in Subsections VII-3.2.1 and 3.2.5. Since the actual retrieval mission is not a normal part of the mission, the costs of retrieval missions are discussed separately in Subsection VII-5.

Only minor changes in satellite design are required to enable LEO retrieval capability of the satellite by the Shuttle. The added cost to the satellite is small and there is no increase in launch cost as the spinner satellite is charged by its length. The projected savings of one point in insurance rate make this APO economically attractive. As pointed out under discussion of insurance, retrievability may be required in order to obtain insurance.

The actual cost for a retrieval mission is not included in this APO. In case of a problem with the satellite, the cost of retrieval would have to be weighed against the value of the retrieved satellite.

3.1.2 GB-OTV Launch to GTO

Use of the ground-based (GB) OTV allows a decrease satellite launch costs, removal of the perigee stage, and a two point reduction in launch insurance. The satellite design has increased cost to allow for the OTV interface, thermal shielding during OTV launch, and additional capability for three axis orientation and spin-up in GTO. Increased mission operations are also required.

The \$12.5 M APO value needs to be significantly more than the fee NASA will charge for use of the GB-OTV in order to create savings for the customer. This is unlikely, even for a shared satellite launch, if the cost of Shuttle transport for the GB-OTV must be paid by each mission. Subsection 4.1.2 estimates fees of \$14 M for use of the GB-OTV.

3.2 Spinner APOs at Station

There are five APOs plus one combination that are envisioned for the spin-stabilized satellite at the Space Station. Their values are shown in Table VII-5 and they are discussed in turn.

3.2.1 LEO Retrieval Capability

The retrieval of satellites that have failed to achieve GEO orbit (on account of perigee motor malfunction or other LEO failure) can be carried out by the OMV and the satellite returned to the Space Station. There is a one point decrease in insurance rates. Although more costly than the baseline system, this APO may be required as a condition of insurance. The real value of this APO depends on the probability of failure, the cost of the retrieval mission, and on whether

	COST (millions of 1985 dollars)						
	Satellite	Shuttle	Perigee	Launch Support	Mission Ops.	Launch Insure	Total
Baseline Satellite	$54.3	$29.9	$3.8	$1.6	$2.6	$23.0	$115.1

	Difference from Baseline (better/<worse>)						APO
APOs at Shuttle	Satellite	Shuttle	Perigee	Support	Mission	Insure	Value
LEO Retrieval	< .1 >	–	–	–	–	1.4	1.1
GB-OTV to GTO	< 1.4 >	8.8	3.1	–	< .3 >	5.0	12.5

	Difference from Baseline (better/<worse>)						APO
APOs at Station	Satellite	Shuttle	Perigee	Support	Mission	Insure	Value
LEO Retrieval	< .6 >	–	–	–	–	1.3	.5
SB-OTV to GTO	< 2.1 >	8.8	3.1	–	< .3 >	6.1	13.0
Checkout	< 1.6 >	–	–	–	–	1.0	< .5 >
Fueling	< 1.2 >	.8	–	–	–	< .1 >	< .4 >
GEO Retrieval	< 1.3 >	–	–	–	–	1.1	< .2 >
Combination	< 2.6 >	8.8	3.1	–	< .3 >	9.5	15.9

Table VII–5: APO Values for Spinner Satellite

there is a satellite repair facility at the Space Station.

3.2.2 SB-OTV Launch to GTO

The same considerations apply to use of the space-based OTV as for the ground-based OTV. However, the costs of providing the space-based OTV are estimated to be substantially less since it does not need to be carried up to LEO in the Shuttle for each mission.

Table VII-6 shows a OTV cost of $10.3 M per satellite for a two satellite launch, which is to be compared with the APO value of $13 M. This is not enough by itself to provide an incentive for this APO.

Spinner Satellite	Launch Cost ($M)	
Launch to GTO	Single	Dual
SB-OTV fee	7.8	7.8
OTV fuel	5.7	9.1
Launch Services	2.7	3.7
OTV Total	16.2	20.6
Shuttle	21.0	42.0
Total	37.2	62.6
Cost per satellite	37.2	31.3

Table VII–6: Launch Costs with SB-OTV

3.2.3 Checkout at Station

The negative value of this APO is due to the increased satellite cost in spite of a one point benefit in insurance rate. However, combination of checkout with an OTV launch is advantageous.

3.2.4 Fueling at Station

The use of fueling has little benefit with the spin-stabilized satellite design since the launch cost continues to be based on satellite length. The spinner satellite cannot be made smaller due to the requirement for solar cell area on its surface. It is unlikely that fuel and fueling costs could be less at the Space Station than on Earth.

3.2.5 GEO Retrieval Capability

The reasons for including retrieval capability in GEO satellites, other than for a failure in LEO, are not clear. The cost of a retrieval mission is high and any deployed appendages may be damaged by an aerobraking maneuver. The safety status of the satellite is another factor that must be considered. Finally, the worth of the retrieved satellite must be taken into account. This APO would be implemented only if there is potential positive benefit.

3.2.6 Combination of Spinner APOs

The following combination of APOs shows the best potential savings for the spinner satellite design:

- Space-based OTV to GTO;
- Checkout at Space Station;
- Fueling;
- GEO Retrieval capability.

If the \$15.9 M APO value is compared with the estimated \$10.3 M cost of the SB-OTV (Table VII-6), \$5.6 M remains to be divided among NASA fees for the other APOs and satellite owner's incentive.

3.3 Discussion of Spinner APOs

The combination spinner APO at the Space Station may show a small incentive for use after NASA fees are paid. There are additional benefits of reliability and versatility to be realized.

4 3-Axis APO Values

The values of APOs for the 3-axis satellite are summarized in Table VII-7 and discussed in turn. The 3-axis satellite design was presented in Subsection IV-3.31. The discussion of 3-axis APO value is divided into two parts: APOs at the Shuttle and APOs at the Space Station.

4.1 3-Axis APOs at Shuttle

There are three APOs plus one combination that are envisioned for the 3-axis satellite at the Shuttle.

4.1.1 LEO Retrieval Capability

The capability to support a future retrieval mission impacts the baseline satellite design. This impact is described here and in Subsections VII-4.2.1 and 4.2.6. Since the actual retrieval mission is not a normal part of the mission, the costs of retrieval missions are discussed separately in Subsection VII-5.

Only minor changes in satellite design are required to support retrieval by the Shuttle. The added cost to the satellite is small and its greater mass slightly increases the Shuttle launch cost. The projected savings of one point in insurance rate make this APO economically attractive. As pointed out under discussion of insurance, retrievability may be required in order to obtain insurance.

The actual cost for a retrieval mission is not included in this APO. In case of a problem with the satellite, the cost of retrieval would have to be weighed against the value of the retrieved satellite.

4.1.2 GB-OTV Launch to GEO

Table VII-7 shows an APO value of \$37.2 M, primarily due to the five point reduction in launch insurance (Table VII-2) and the reduced Shuttle charges for launch of the satellite without perigee stage. (However, the NASA fee will include Shuttle charges for launching the GB-OTV.) The mission cost savings are based on the

	COST (millions of 1985 dollars)						
	Satellite	Shuttle	Perigee	Launch Support	Mission Ops.	Launch Insure	Total
Baseline Satellite	$64.6	$35.4	$6.9	$1.6	$2.6	$27.8	$138.8

APOs at Shuttle	Difference from Baseline (better/<worse>)						APO Value
	Satellite	Shuttle	Perigee	Support	Mission	Insure	
LEO Retrieval	< .1 >	–	–	–	–	1.7	1.3
GB-OTV to GEO	3.9	19.3	6.3	–	.8	13.5	37.2
Deploy Appendage	–	–	–	–	.3	1.8	1.7
Combination	3.9	19.3	6.3	–	1.0	14.7	38.8

APOs at Station	Difference from Baseline (better/<worse>)						APO Value
	Satellite	Shuttle	Perigee	Support	Mission	Insure	
LEO Retrieval	< .7 >	–	–	–	–	1.6	.7
SB-OTV to GEO	3.4	19.3	6.3	–	.8	15.6	39.5
Deploy Appendages	< 1.0 >	–	–	–	.3	1.6	.7
Checkout	< 1.8 >	–	–	–	–	1.3	< .4 >
Fueling	< 1.6 >	–	–	–	–	< .4 >	< 1.6 >
GEO Retrieval	< 1.1 >	–	–	–	–	1.5	< .3 >
Combination	2.1	19.3	6.3	–	1.0	17.6	41.2

Table VII–7: APO Values for 3-axis Hybrid Satellite

Hybrid Satellite Launch to GEO	Launch Cost ($M) Single	Dual
GB-OTV fee	7.8	7.8
Aft carrier fee	2.4	2.4
Propellant cost	11.2	14.4
Launch Services	2.7	3.7
OTV total	24.1	28.3
Sat. to LEO	16.1	32.2
GB-OTV to LEO	35.4	35.4
Shuttle total	51.5	68.7
Total cost	75.6	97.0
Cost per satellite	75.6	48.5

Table VII–8: Launch Costs with GB-OTV

deletion of the numerous transfer orbit maneuvers that are currently used by the business-as-usual scenario. These orbit manuevers are now under NASA control and billed as OTV launch services.

Table VII-8 estimates the costs for use of the GB-OTV. Note that there is a $2.4 M service charge for using the aft cargo carrier (at the end of the external tank) for carrying the GB-OTV. These charges reflect the fact that the external tank must be carried into LEO. For a two satellite launch, the OTV charges are $14 M per satellite and the Shuttle charges for the GB-OTV are $18 M per satellite for a total $32 M compared to the $37.2 M APO value. $5 M remains for owner's incentive, and this APO may be feasible.

The OTV charges are based on a 1 G launch and would be approximately $2 M higher for the low G launch required for satellites with deployed appendages.

4.1.3 Deploy Appendages

The deployment of appendages such as solar arrays, antennas, and equipment booms in Space by EVA will increase reliability of deployment and reduce the cost of ground-commanded deployment sequences. However, there will be increased cost due to ground simulations of EVA activity by NASA. Once appendages are deployed, a low thrust perigee stage must be used.

The primary economic value of this APO comes from the projected one point savings in launch insurance. It is clearly beneficial for commercial satellite launches, particularly of satellites with many or large appendages, to have EVA assisted deployment. The question is whether NASA can supply the required EVA activity within the relatively small ($1.7 M) value of the APO.

Another important benefit may be the allowing of new capability. The constraint of packaging to allow unfolding antennas and solar arrays is removed, and large or numerous appendages can be sent up separately in the Shuttle. This factor has not been considered in the Model.

4.1.4 3-Axis Combination at Shuttle

The combination of appendage deployment with a low thrust OTV launch results in an APO value of $38.8 M. However, the additional fuel required for a low thrust OTV launch will be more than the value of the deployment. Thus, unless there are unusual difficulties with deployment, business-as-usual satellites will prefer OTV launch without deployment.

4.2 3-Axis APOs at Station

There are six APOs plus one combination that are envisioned for the 3-axis satellite at the Space Station, as shown in Table VII-7. They will be discussed in turn.

A further two APOs are also discussed but not analyzed by the Financial Model. They are (1) assembly at the Space Station, and (2) servicing in GEO by a remote servicing module carried by the OMV via the OTV.

4.2.1 LEO Retrieval Capability

The retrieval of satellites that have failed to achieve GEO orbit (on account of perigee motor malfunction or other LEO failure) can be carried out by the OMV and the satellite returned to the Space Station. There is a one point decrease

Hybrid Satellite Launch to GEO	Launch Cost ($M) Single	Dual
SB-OTV fee	7.8	7.8
Propellant cost	20.1	25.4
Launch Services	2.7	3.7
OTV total	30.6	36.9
Shuttle cost	16.1	32.2
Total cost	46.7	69.1
Cost per satellite	46.7	34.5

Table VII–9: Launch Costs with SB-OTV

in insurance rates. Although more costly than the baseline system, this APO may be required as a condition of insurance. The real value of this APO depends on the probability of failure, the cost of the retrieval mission, and on whether there is a satellite repair facility at the Space Station.

4.2.2 SB-OTV Launch to GEO

Due to the launch cost saved by not having to carry the OTV up on the Shuttle, the potential savings for the space-based OTV are greater than for the ground-based OTV. The $39.5 M APO value is primarily due to a seven point insurance benefit (Table VII-2) and savings in Shuttle launch costs for the perigee motor.

Table VII-9 estimates costs for use of the SB-OTV at $18.5 M per satellite for a two satellite launch. There is a potentially large incentive of $21.5 M for use of the OTV.

A graphic comparison of launches is shown in Figures VII-1, 2, and 3 of the 1995 hybrid 3-axis satellite for the following cases:

1. Business-as-usual scenario; single hybrid satellite plus upper stage on Shuttle.
2. Single satellite on Shuttle and OTV.
3. Two satellites on Shuttle and OTV.

Use of the OTV is more expensive than a conventional upper stage for a single satellite launch, but results in substantial savings for a dual satellite launch. The OTV has sufficient capacity for a triple or even quadruple hybrid satellite launch.

4.2.3 Deploy Appendages at Station

This APO is more realizable than its Shuttle-based counterpart. EVA time is expected to cost less at the Space Station, or perhaps IVA can take the place of EVA. There is also less time constraints on operations at the Space Station than at the Shuttle.

4.2.4 Checkout at Station

This APO is not advantageous as a stand alone capability. Additional costs would be incurred for use of the Space Station. However, this APO does offer worthwhile advantages when combined with other APOs.

4.2.5 Fueling at Station

Fueling satellites from the Space Station requires added complication in satellite design and gives limited benefits. There is no positive impact on insurance rates.

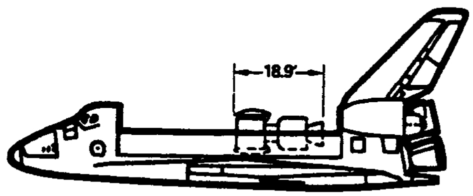
4.2.6 GEO Retrieval

The reasons for including retrieval capability in GEO satellites, other than for a failure in LEO, are not clear. The cost of a retrieval mission is high and any deployed appendages may be damaged by an aerobraking manuever. The safety status of the satellite is another factor that must be considered. Finally, the worth of the retrieved satellite must be taken into account. This APO would be implemented only if there potential positive benefit.

4.2.7 Combination of 3-Axis APOs

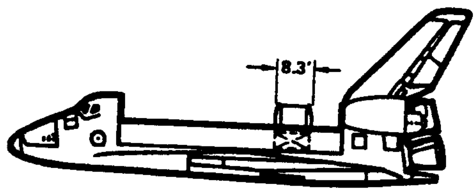
The following combination of APOs is considered:

- Space-based OTV to GEO;
- Deploy appendages at Space Station;
- Fueling at Space Station;
- Checkout at Space Station;



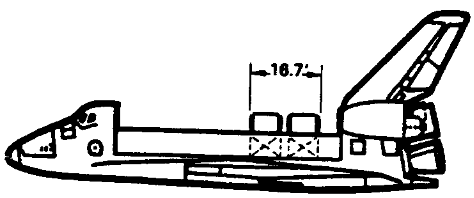
Shuttle	$35.4 M
Perigee	$ 6.9 M
Total	$42.3 M

Figure VII–1: Business-as-Usual Launch



Shuttle	$16.1 M
OTV fees	$10.5 M
OTV fuel	$20.1 M
Total	$46.7 M

Figure VII–2: One Satellite OTV Launch



Shuttle	$32.2 M
OTV fees	$11.5 M
OTV fuel	$25.4 M
Total (2)	$69.1 M
Total (1)	$34.5 M

Figure VII–3: Two Satellite OTV Launch

- Retrieval capability.

The $41 M APO value is considerably larger than the $18.5 M fees incurred by use of the SB-OTV for transport to GEO. The fee charged by NASA for checkout and deployment of appendages at the Space Station should be considerably less than the $22 M difference, leaving margin for a 1% improvement in DTRR (equivalent to $12 M APO value).

4.2.8 Assembly at Space Station

Economic assessment of an assembly APO has not been included due to the range of assembly options and the complete change of design that may be required. Assembly for initial missions does not seem to show major advantages for the baseline-sized satellite. Satellites requiring assembly will generally be unique designs that cannot be used for a wide range of commercial uses.

4.2.9 GEO Servicing

Servicing APO economic assessments have not been included due to the lack of basis for initial servicing missions. Current satellite hardware generally has similar expected lifetimes (7 to 10 years). Although much equipment has survived space environments past the predicted lifetimes, much has not. The choice of which equipment to be made replaceable is highly subjective. Results obtained from an economic evaluation would also lack proper reference.

Initial use of GEO servicing will be dependent on the cost of a servicing mission versus the cost of building new satellites.

4.3 Discussion of 3-Axis APOs

Use of the SB-OTV gives large positive benefits, justifying use of the Space Station. Once at the Station to use the OTV, other APOs can be profitably accomplished.

The advantage that OTV use gives is so dramatic that a special case of a large (2,200 kg) satellite is analyzed in Subsection VII-6.

C-2

5 Retrieval Missions

The economics of retrieval missions are examined for the 1995 spinner and the 1995 Hybrid satellite designs. The dominating costs are those for transportation (retrieval and relaunch) and re-insurance.

The discussion is divided into missions using the Shuttle and those using the Space Station. Two types of missions are possible; (1) repair-in-space missions and (2) retrieval, transport-to-Earth for repair, and relaunch. Missions attempting repair in space may include the capability to return the satellite to Earth for repair or salvage.

5.1 Insurance of Retrieval Missions

Insurance is an important factor in the retrieval decision. Present day satellite insurance policies pay the insurer the full value of the satellite upon loss. The satellite, as with the Palapa and Westar satellites retrieved by the Shuttle, becomes the property of the insurance company after failure. Thus the insurance company makes the retrieval or salvage decisions in this scenario, and has the problem of disposing of the repaired satellite. The retrieval decision will be based on the economic value of the repaired satellite and the probability of success of the mission.

Once the capability for satellite retrieval exists, the satellite insurance policy will change such that the ownership of the satellite will remain with the original owner while insurance covers retrieval and repair attempts. The insurance company will again exercise control over retrieval, repair, relaunch or salvage operations.

The cost of insurance during retrieval missions will continue to be based on the value of the satellite and the probability of accident during the mission. The insurance assumptions of this subsection on retrieval do not have a firm basis, but are our best estimates without interviews with insurance brokers.

5.2 Shuttle Missions in LEO

A Shuttle retrieval mission has two possible scenarios; (1) repair at the Shuttle and (2) return to Earth for repair and then relaunch. These missions require advance planning, training, and special equipment, and thus a "new" Shuttle mission.

The mission that originally launched the satellite is not prepared for retrieval unless the preparation cost is included for all launches. This would be unrealistic since the historical failure rate is only 1 in 6, including failures that are not retrievable.

5.2.1 Repair at the Shuttle

Retrieval can be attempted for failures that occur prior to a perigee firing maneuver. The scenario assumes that the satellite is placed on a cradle (brought up by the Shuttle) in the Shuttle bay for repair. Some of these failures may be simple to repair and the satellite can be released and the perigee stage fired.

The repair-at-Shuttle mission has the following steps:

1. Plan and train for retrieval
2. Shuttle to LEO with cradle
3. Retrieve satellite
4. Inspect satellite; make repair decision
5. Repair satellite
6. Release satellite
7. Wait to verify success

If the repair attempt is unsuccessful, the decision could be made to retrieve the satellite to Earth for repair or salvage. (There may be future requirements to remove "junk" from orbit or at minimum place in a space junkyard.) As the cost for the retrieval has been spent, the satellite can be salvaged to Earth at this stage in the mission at little extra cost. If repair on Earth is chosen, the cost for the repair and relaunch are as shown in the next subsection.

Table VII-10 summarizes the cost of the repair mission. The Shuttle cost assumes that in addition to a repair kit and grapple fixtures, a cradle is transported from Earth to LEO so that the

Item	Spinner	3-Axis
Shuttle rendezvous	29.9	35.4
Retrieval/release	2.3	2.3
Ground operations	.5	.5
Mission operations	2.0	2.0
Replaced parts	0	0
Total Cost ($M)	34.7	40.2

Table VII–10: Repair-at-Shuttle Mission Cost

satellite can be retrieved if necessary. A repair-only attempt would utilize less space in the Shuttle and have less Shuttle cost. The capital costs of the replaced parts of the satellite are not included, but should not be large considering the limited capability for repair at the Shuttle.

There are no additional insurance costs for this mission. Since the cost of the repair mission is assumed to be paid by the insurance company, the value of the satellite remains the same.

5.2.2 Repair on Earth

The repair-on-Earth mission has the following steps:

1. Plan and train for retrieval
2. Shuttle to LEO with cradle
3. Retrieve satellite
4. Return satellite to earth
- Make repair/salvage decision
- (Satellite undergoes repair and checkout)
5. Relaunch satellite on later mission

Table VII-11 summarizes the cost of this mission. The capital costs of the replaced parts of the satellite are not included in the estimated $5 M minimum for handling and checkout. Depending on the nature of the failure and design of the satellite, these costs may be much higher. The relaunch cost includes Shuttle costs, new perigee motor, launch support, and mission operations as per Table VII-5 for the spinner satellite and Table VII-7 for the 3-axis satellite.

Item	Spinner	3-Axis
Shuttle	29.9	35.4
Retrieval	2.0	2.0
Ground operations	.5	.5
Mission operations	1.0	1.0
Retrieval Total	33.4	38.9
Repair cost	> 5.0	> 5.0
Relaunch cost	37.9	46.5
Re-insurance	3.8	4.6
Total ($M)	> 80.1	> 95.0

Table VII–11: Shuttle Retrieval, Earth Repair

The insurance cost for the relaunch is figured at 3.2% of the value of the satellite. This is the pro rata risk (plus 0.6 points overhead), based on Table VII-1, of the repeated Shuttle launch.

5.3 Missions with Space Station

Retrieval missions with the Space Station can use the OMV for LEO retrieval and the OTV for GEO retrieval. Repair is made at the Space Station if possible; otherwise transport to earth via Shuttle for repair and then relaunch on the Shuttle is required. There is an economic incentive to repair at the Space Station as around $80 M in transportation-to-Earth and relaunch costs are eliminated. A final option is to retrieve and salvage (one-way return to earth).

5.3.1 LEO Retrieval & Repair at Station

For reasons mentioned in the previous subsection, it does not seem to be feasible to offer retrieval on the same Shuttle flight as the launch. However, retrieval from LEO by the OMV and transport to the Space Station can occur within a day of failure. It is very important in order to place the satellite in a protective environment and to turn it off. This saves in hardware lifetime and avoids the damaging effects of atomic oxygen and a rapidly changing thermal environment.

The mission involves the following steps:

1. OMV retrieves satellite to Space Station

Item	Spinner	3-Axis
OMV fee (capture)	3.0	3.0
Station fees	> 2.5	> 2.5
Ground operations	.3	.3
Repair kit launch	.2	.2
Ground simulations	1.0	1.0
OMV fee (release)	2.0	2.0
Total Cost ($M)	> 9.0	> 9.0

Table VII–12: LEO Retrieval/Repair at Station

2. Inspect satellite; make repair decision
3. Deliver repair kit to Space Station
4. Repair satellite
5. Relaunch satellite via OMV

Table VII-12 summarizes the cost of this mission. The capital costs of the replaced parts of the satellite are not included. There are no further insurance costs.

5.3.2 LEO Retrieval & Return-to-Earth for Repair

This mission involves the following steps:

1. OMV retrieves satellite to Space Station
2. Inspect satellite; make return-to-earth decision
3. Return satellite to earth

   – (Satellite undergoes repair and checkout)

4. Relaunch satellite via Shuttle

Table VII-13 summarizes the cost of this mission. The capital costs of the replaced parts of the satellite are not included.

The costs for the return-to-Earth portion of this mission would be the same for a satellite retrieved from GEO and brought to the Space Station as for a satellite retrieved from LEO.

Item	Spinner	3-Axis
OMV use fee	3.0	3.0
Station fees	2.0	2.0
Ground operations	.3	.3
Repair kit launch	.2	.2
Ground simulations	1.0	1.0
Mission operations	1.0	1.0
Shuttle return	21.1	16.1
Repair	> 5.0	> 5.0
Re-launch	37.9	46.5
Reinsurance	3.8	4.6
Total Cost ($M)	> 75.3	> 79.7

Table VII–13: Leo Retrieval to Station, Return to Earth for Repair.

5.3.3 GEO Retrieval & Repair at Station

The geosynchronous retrieval is combined with another OTV mission to reduce costs. The costs assume a shared mission with a two satellite launch and one other satellite retrieved. It is assumed that some lightweight adaptor is carried and used to capture the satellite to be retrieved. The retrieval mission is not the same as the OTV mission that launches the satellite.

This mission involves the following steps:

1. Make retrieval decision
2. SB-OTV to GEO
3. Retrieve satellite
4. Inspect satellite; make repair decision

   – (Satellite undergoes repair and checkout)

5. Relaunch satellite to GEO via SB-OTV

Table VII-14 summarizes the cost of this mission. The cost of repair and relaunch is variable depending on the state of the satellite. A new perigee and apogee system (including fuel) and Space Station repair costs would exist as a minimum.

Item	Spinner	3-Axis
SB-OTV use fee	2.0	2.0
OTV fuel	48.0	48.0
Ground operations	.5	.5
Mission operations	1.0	1.0
Total Cost ($M)	51.5	51.5

Table VII–14: GEO Retrieval, Repair at Station Mission Costs.

5.4 Summary of Retrieval Missions

Considering the total insured cost of the 1995 satellites range from $115 M for the spinner to $138 M for the 3-axis design, it is worth expenditure to fix or salvage a satellite. The repair of satellites at the Space Station, if possible, is much less costly than ground repair with its Shuttle transportation charges and re-insurance expense. GEO retrieval for ground repair does not appear to be economically feasible.

Figures VII-4 and VII-5 illustrate the cost elements of the different retrieval missions using the Space Station for the 1995 hybrid satellite (total capital cost $138 M). For a failure in LEO, repair at the Space Station costs $9 M versus $95 M for transport to ground for repair and relaunch to LEO. For a GEO failure repair at the Space Station costs $85 M for OTV launch and $103 M for launch via a new perigee motor transported from Earth. A GEO retrieval to Earth for repair and relaunch costs a prohibitive $144 M, more than the value of the satellite.

6 Hectosat Economics

The capital cost of the large 3-axis satellite design which is called *Hectosat* for its 100 transponder payload is summarized in Table VII-16. Details of the design were presented in Subsection IV-4.

This design exploits the large carrying capacity of the OTV. Thus the only APO analyzed is the use of the space-based OTV to transport Hectosat from the shuttle to geostationary orbit.

	Launch Cost ($M)	
Centaur Perigee	Single	Dual
Shuttle Cost	95	95
Centaur Cost	60	60
Launch Services	4	5
Total Cost	159	160
Cost per satellite	159	80

OTV Perigee	Single	Dual
Shuttle Cost	20.0	40.0
OTV Use Fee	7.8	7.8
Propellant Cost	20.6	26.1
Launch Services	2.7	3.7
Total Cost	51.1	77.6
Cost per satellite	51.1	38.8

Table VII–15: Hectosat Launch Costs

6.1 Launch Costs

Table VII-15 gives Centaur and OTV launch costs for Hectosat. The Centaur G is the only upper stage that has enough capacity to transport the 2,200 kg Hectosat from LEO to GEO. In fact the Centaur upper stage has enough capacity to carry two Hectosats. The cost of the Shuttle launch is the same for Centaur plus one or two satellites; i.e. a full load for pricing purposes.

The cost of the Shuttle launch using the OTV is greatly reduced since, unlike the Centaur, the space-based OTV is not carried up in the Shuttle for each use. The Shuttle charges are determined by the length occupied by the satellite in the Shuttle.

The major expense is the cost of fuel for the OTV, as shown in Table VII-16 and discussed in Subsection VII-2.3. There is a large advantage in launching two satellites at once on the OTV.

6.2 Economic Performance

Table VII-16 gives a total cost of $215.4 M for the Centaur launch versus $149.8 M for the OTV launch, a difference of $65.6 M in capital expenditures between the two launch methods. Note that this is not the APO value as for the spinner

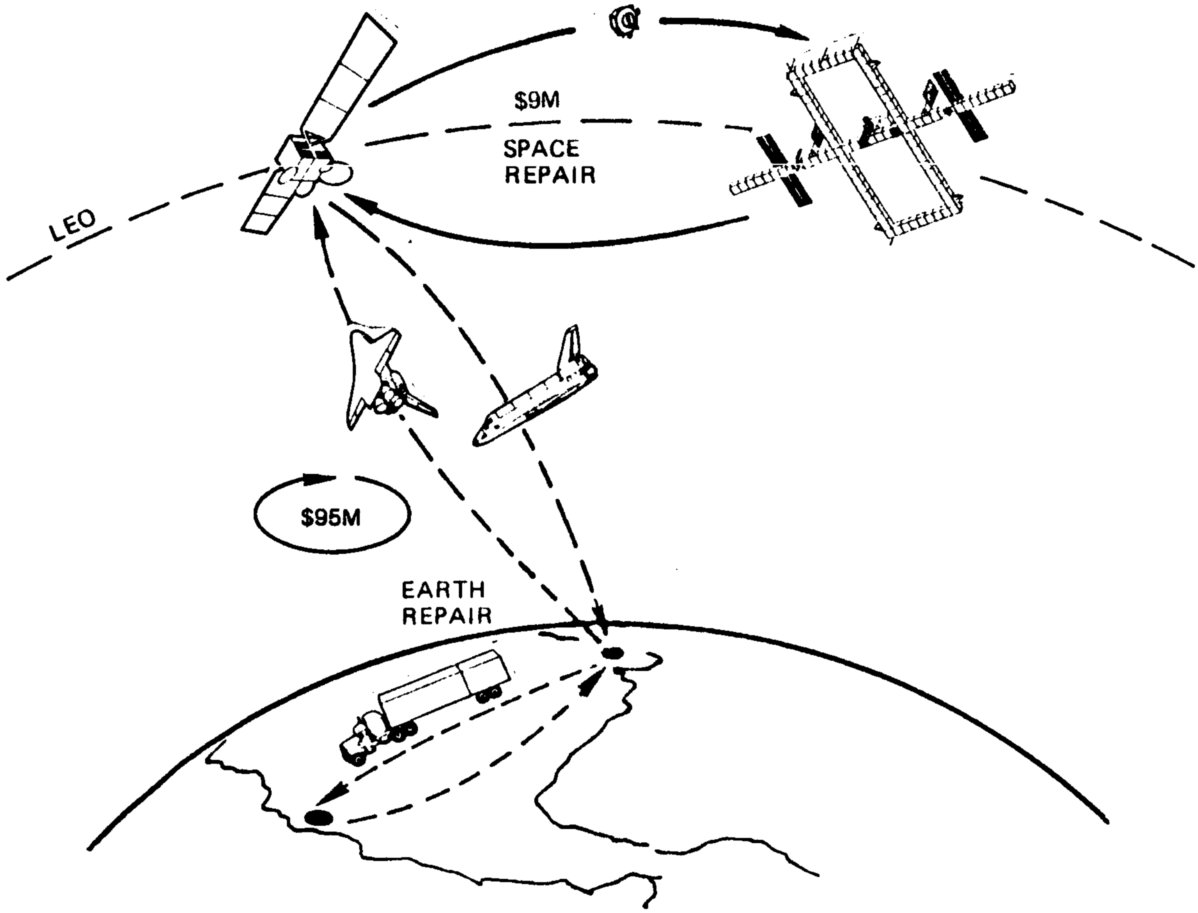


Figure VII–4: Schematic of LEO Retrieval Costs

Launch Vehicle	COST (millions of 1985 dollars)						
	Satellite	Shuttle	Perigee	Launch Support	Mission Ops.	Launch Insure	Total
Centaur G	$88.1	$47.5	$32.5	$1.6	$2.6	$43.1	$215.4
Space-based OTV	$88.1	$20.0	$18.8	$1.6	$1.8	$19.5	$149.8

Table VII–16: Capital Cost for 3-axis Large Satellite

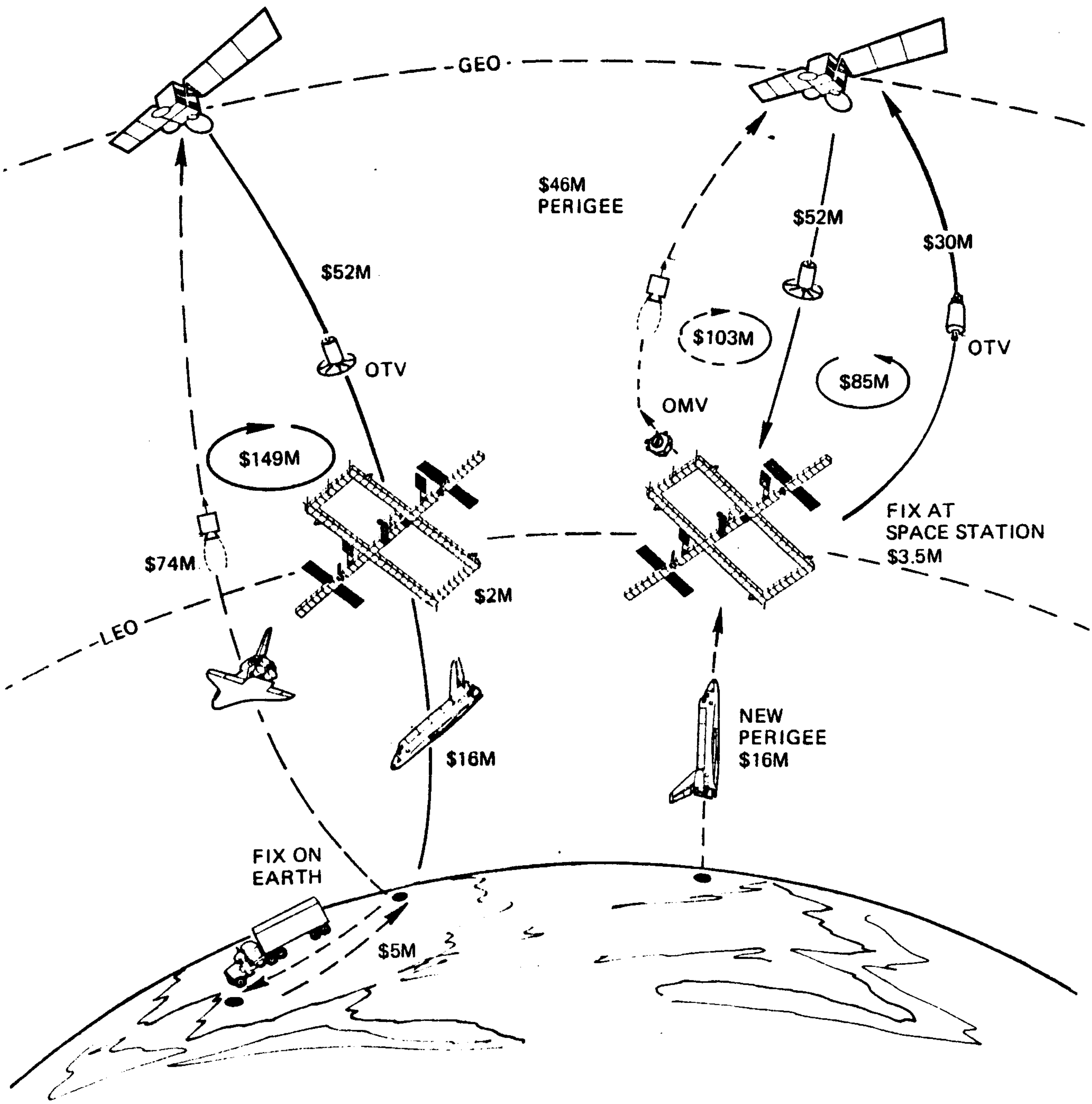


Figure VII–5: Schematic of GEO Retrieval Costs

Satellite	Upper Stage	DTRR Return	Trans. Price $M/yr
3-Axis Ku	Pam D2	18.9	1.27
Hybrid	Ford	21.9	1.27
Hectosat	Centaur	23.0	1.04
Hectosat	SB-OTV	23.0	.78

Table VII–17: Hectosat Economic Performance

and 3-axis satellites. The charge for the OTV launch has been included in the cost as per Table VII-15.

The economics of the baseline case, the dual satellite launch via Centaur G, is reported in Subsection V-6 and in the nine pages of Table B-4 in Appendix B. Table VII-17 compares the economic performance of the OTV launch with the baseline Centaur perigee stage. A premium of 1% DTRR return is allowed for Hectosat versus the average 1995 return due to its large size and consequent large risk for the owner and operator.

In order to keep the DTRR return at the desired level, a 18% reduction in transponder price is required for the baseline Centaur launched satellite, and a further 25% for a total of 39% reduction for the OTV-launched Hectosat. These dramatic transponder price reductions give a significant financial advantage to large satellites launched with the OTV.

7 Conclusion

Use of the space-based OTV for transport of two or more 3-axis satellites from LEO to GEO is the high value APO that can make commercial satellite operations with the Space Station a reality. Once at the Space Station, other APOs of marginal value but important to the particular mission can be done.

Table VII-18 summarizes the economic value of the individual APOs for the spinner and 3-axis satellites. The major reasons for economic value as follows:

- Savings in STS launch costs due to decrease in mass.
- Savings in insurance costs (20% nominal rate).
- Increase in satellite cost.

The combination APOs have an additional value due to the fact that some of the same satellite equipment is required for different APOs.

A preliminary evaluation of a modular satellite that would be assembled at the Space Station and be capable of being serviced in GEO is given in Subsection VIII-4.

APOs at Shuttle	Spinner Satellite ($115 M)			3-Axis Satellite ($139 M)		
	Value	$M	Major Reasons	Value	$M	Major Reasons
Capability for LEO Retrieval	yes	1.1	Insurance -1%	yes	1.3	Insurance -1%
GB-OTV from LEO to GTO	yes	12.5	Insurance -2%	–	–	LEO-GEO better
GB-OTV from LEO to GEO	–	–	Spinner design	yes	37.2	Insurance -5%
Deploy appendages	no	–	Spinner design	yes	1.7	Insurance -1%
3-Axis Combination	–	–		yes	38.8	STS cost/Ins. -6%

APOs at Space Station	Spinner Satellite ($115 M)			3-Axis Satellite ($139 M)		
	Value	$M	Major Reasons	Value	$M	Major Reasons
Capability for LEO Retrieval	yes	.5	Insurance -1%	yes	.7	Insurance -1%
SB-OTV from LEO to GTO	yes	13.0	Insurance -2%	–	–	LEO-GEO better
SB-OTV from LEO to GEO	–	–	Spinner design	yes	39.5	Insurance -5%
Deploy satellite appendages	no	–	Spinner design	no	–	Sat. cost increase
Checkout of satellite	no	–	Spinner design	no	–	Sat. cost increase
Add fuel to satellite	no	–	Spinner design	no	–	Sat. cost increase
Capability for GEO Retrieval	no	–	Sat. cost increase	yes	1.3	Insurance -1%
Spinner Combination	yes	15.9	STS cost/Ins. -6%	–	–	
3-Axis Combination	–	–		yes	41.2	STS cost/Ins. -9%

Table VII–18: Summary of APO Economics

Section VIII
SPACE STATION SCENARIOS

1 Introduction

This section presents the Task 4 results describing three communications satellite system operating scenarios implementing different combinations of APOs. The economic performance of these scenarios is evaluated and compared to the baseline performance. Finally the sensitivity of the results to different insurance and launch cost assumptions is analyzed.

The following scenarios are chosen for evaluation:

- Spinner satellite scenario:
  - Checkout at Station
  - Fueling at Station
  - Space-based OTV to GTO
  - Retrieval capability from GEO
- 3-axis satellite scenario:
  - Deploy appendages at Station
  - Checkout at Station
  - Fueling at Station
  - Space-based OTV to GEO
  - Retrieval capability from GEO
- Assembly/servicing scenario:
  - Assemble satellite at Station
  - Checkout at Station
  - Fueling at Station
  - Space-based OTV to GEO
  - Service satellite in GEO

The spinner satellite APO scenario is not economically attractive but is included for completeness. It is our belief that satellites will have a 3-axis design in order to best utilize the capabilities of the Space Station.

The assembly/servicing scenario requires a completely new satellite design which will not evolve until the Space Station is in orbit. Its IOC (initial operational capability) is unlikely to be 1995 but rather the year 2000.

2 Spinner Satellite Scenario

2.1 Description

The following APOs are utilized with the 1995 spinner satellite design:

- Checkout at Station
- Fueling at Station
- Space-based OTV to GTO
- Retrieval capability from GEO

The checkout APO requires additional satellite costs and Space Station costs in time and equipment. A hypothesized one point reduction in insurance gives this APO value when combined with an OTV launch. Operationally, it is required to verify the health status of a satellite after operations at the Space Station. Thus it is likely that checkout will be required by the insurance company.

Even though fueling has no benefit for the spinner satellite design, it is included in this scenario in order to satisfy possible operational constraints on storing or moving fueled satellites at the Space Station. (The volume of the spinner design is such that carrying the satellite empty to LEO does not save money for a shuttle launch.)

The space-based OTV is used to carry the satellite to GTO (geostationary transfer orbit).

The reusable OTV is more reliable (3 point reduction in insurance) and avoids the necessity of carrying an expendable rocket motor from earth to LEO. The OTV fuel must still be carried from Earth to LEO, and the OTV economics are dominated by the cost of this fuel. Since appendages are not deployed, the OTV can use high thrust.

Retrieval capability from GEO (or GTO) requires additional mass on the satellite for support during retrieval operations. A one point reduction in insurance rate is hypothesized for this capability. Future insurance policies may require this capability. As analyzed in Subsection VII-5, there may be substantial benefits if the satellite fails in a manner that is retrievable.

Capital Expenditure	Cost ($M 1985) Baseline	Station Scenario
Satellite	54.3	56.9
STS Launch	29.9	21.1
Perigee stage	3.8	.7
Launch support	1.6	1.6
Mission ops.	2.6	2.3
Insurance	23.0	13.5
Total	115.1	96.1
OMV/OTV	–	10.3
Station support	–	3.0
Insurance	–	2.2
Total	115.1	111.6

Table VIII–1: Spinner Scenario Economics

2.2 Economic Evaluation

Table VIII-1 gives a comparison of the capital expenditures for the spinner scenario with the Space Station compared to the baseline spinner scenario (described in Subsections IV-3.1, V-3, and Table B-1 of Appendix B). A total insurance benefit of 6 points (a rate change from 20% to 14%) is hypothesized this scenario. The APO value methodology of Section VII is not used. The cost of the OTV launch is obtained from Table VII-5, and the Space Station support costs for handling, checkout, and fueling are estimated.

Launch insurance is 20% for the baseline case and 14% for the Space Station scenario. Insurance appears twice in the table, first for the upper group of capital expenditures and second for the lower group.

The result is a $3.5 M savings for the scenario versus the baseline satellite. The Financial Model indicates this corresponds to a 0.2 point increase in the rate-of-return (DTRR) from 18.9% for the baseline to 19.1% for the spinner scenario with the Space Station. Considering the uncertainties in the inputs to this calculation, this scenario has marginal value.

3 3-Axis Satellite Scenario

3.1 Description

The following APOs are utilized with the 1995 hybrid 3-axis satellite design:

- Deploy appendages at Station
- Checkout at Station
- Fueling at Station
- Space-based OTV to GEO
- Retrieval capability from GEO

The deployment of appendages APO requires Space Station support costs for IVA and possibly EVA operations. The satellite cost is also increased, but is offset by a hypothesized one point decrease in insurance rates. Once appendages are deployed, the OTV must be used in low thrust (0.1 G) mode for transport to GEO.

The checkout APO requires additional satellite costs and Space Station costs in time and equipment. A hypothesized one point reduction in insurance gives this APO value when combined with an OTV launch. Operationally, it is required to verify the health status of a satellite after operations at the Space Station. Thus it is likely that checkout will be required by the insurance company.

Fueling increases satellite cost and has no insurance benefit. It is included in this scenario in order to satisfy possible operational constraints on storing or moving fueled satellites at the Space Station.

The space-based OTV is used to carry the satellite to GEO (geostationary orbit) in a low thrust mode (0.1 G). The reusable OTV is more reliable (7 point reduction in insurance) and avoids the necessity of carrying an expendable rocket motor from earth to LEO. The OTV fuel must still be carried from Earth to LEO, and the OTV economics are dominated by the cost of this fuel.

Retrieval capability from GEO requires additional mass on the satellite for support during retrieval operations. A one point reduction in insurance rate is hypothesized for this capability. Future insurance policies may require this capability. As analyzed in Subsection VII-5, there may be sustantial benefits if the satellite fails in a manner that is retrievable.

3.2 Economic Evaluation

Table VIII-2 gives a comparison of the capital expenditures for the 3-axis scenario with the Space Station compared to the baseline 3-axis scenario (as described in Subsections IV-3.3, V-5, and Table B-3 of Appendix B). A total insurance benefit of 9 points (a rate change from 20% to 11%) is hypothesized this scenario. The cost of the OTV launch is obtained from Table VII-7. Space Station support costs for handling, deployment, checkout, and fueling are estimated.

The result is a $21.5 M savings for the scenario using the Space Station versus the baseline case. The Financial Model indicates this corresponds to a 1.4 point increase in the rate-of-return (DTRR) from 21.9% for the baseline to 23.3% for the 3-axis scenario with the Space Station. This indicates substantial economic value.

Capital Expenditure	Cost ($M 1985) Baseline	Station Scenario
Satellite	64.6	62.5
STS Launch	35.4	16.1
Perigee stage	6.9	.6
Launch support	1.6	1.6
Mission ops.	2.6	1.6
Insurance	27.8	10.2
Total	138.8	92.6
OMV/OTV	-	18.5
Station support	-	3.5
Insurance	-	2.7
Total	138.8	117.3

Table VIII–2: 3-Axis Scenario Economics

4 Assembly/Servicing Scenario

4.1 Description

The following APOs are utilized with the 1995 hybrid 3-axis satellite payload that is incorporated into a redesigned satellite:

- Assemble satellite at Space Station
- Checkout at Space Station
- Fueling at Space Station
- Space-based OTV to GEO
- Service satellite in GEO

In order to be serviced in orbit by an OMV plus servicer front end, the satellite must be designed in a different manner. The concept is to have a satellite design with modules that are replaced during servicing. This leads to a less highly integrated satellite design that consists of pieces that can be transported separately and then assembled at the Space Station. Thus the concept of servicing a satellite leads to the potential for assembly.

The servicing mission is planned to occur after nine years and to result in extension of the satellite life by another nine years. The following are examples of items would be replaced by the servicing mission:

- Batteries
- Momentum wheels
- Station-keeping fuel

Capital Expenditure	Cost ($M 1985)		
	Baseline	Scenario	
	1st or 2nd	1st	2nd
Satellite	62.5	68.9	34.8
STS Launch	16.1	15.4	8.0
Perigee stage	.6	.6	.3
Launch support	1.6	1.6	.5
Mission ops.	1.6	1.6	1.6
Insurance	10.2	10.9	5.6
Total	92.6	99.0	50.8
OMV/OTV	18.5	19.9	16.5
Station support	3.5	5.0	3.0
Insurance	2.7	3.1	2.4
Total	117.3	127.0	72.7

Table VIII–3: Assembly/Servicing Economics

- Thermal control panels
- Transponder subsystem

The modular satellite design would be 10% heavier than the baseline satellite of the same capacity. The servicing mission would replace 40% of the mass of the modular satellite.

4.2 Economic Evaluation

Table VIII-3 gives a comparison of the capital expenditures for an 18 year assembly/servicing scenario with the Space Station compared to a baseline scenario with two successive hybrid 3-axis satellite launches each having a nine year lifetime. The baseline scenario uses the 1995 3-axis hybrid satellite with 9 year lifetime and scenario per Subsection VIII-3. It is assumed that the second satellite has the same cost as the first.

The insurance rate is assumed to be the same (11%) for assembly/servicing scenario as for the baseline case. OTV launch costs are based on the same assumptions as Table VII-7. Space Station support costs for the initial assembly and subsequent servicing mission are estimated.

An important assumption of the 18-year Financial Model is that revenues are not inflated while costs are inflated at 4% per year. This was done to reflect the long term trend of decreasing transponder prices. Other Model assumptions are as described in Section II.

The initial capital expenditure is $10 M more but the second launch is $45 M less than the baseline approach. A simple way to evaluate the economics is to consider that $10 M was spent 9 years earlier in order to save (or earn) $45 M. This is a return of 18.2% per year, which is less than the 23.3% rate-of-return (DTRR) for 3-axis (10 yr) satellite scenario. The use of the Financial Model for 18 yr scenarios gives 21.8% return for the baseline (two successive 9 yr satellites) versus 21.0% rate-of-return for the 18 yr assembly/servicing scenario.

The conclusion is that the economics of the assembly/servicing scenario are less favorable than launching two successive conventional satellites with the OTV. However, our satellite costs derived using Price H are based on a very preliminary design of a assemblable, servicable satellite. We recommend that more work be done on design of such a satellite. In particular, relaxation of constraints on compactness may lead to substantial savings in integration and test costs.

5 Sensitivity Analysis

5.1 Introduction

The major uncertainties in the scenario economics compared to the baseline case lie in the areas of insurance costs and launch costs. Using the 3-axis scenario (Table VIII-2) as an example, these costs are varied through a reasonable range and their effect on economic performance assessed.

A major study assumption is that changes in satellite mass due to APOs are not used to alter the payload (i.e. number of transponders). The 3-axis scenario results in a 31 kg mass savings for the satellite. The effect on economic performance of adding this mass in transponders is calculated.

5.2 Launch Insurance

Launch insurance considerations are discussed at length in Subsection VII-2.2. The critical point is the difference, if any, between the Space

3-Axis Satellite	Cost ($ M)	Rate-of-return (%)
Baseline (20%)	138.8	21.9
Scenario (11%)	117.3	23.3
Scenario (20%)	130.5	22.5

Table VIII–4: Influence of Insurance Rate

Station scenario and the baseline case insurance rate. The scenarios assume a 6 point and a 9 point difference respectively for the spinner and 3-axis scenarios.

If it is assumed there is no difference in insurance rates due to the scenarios, the cost of the spinner scenario increases by $8.3 M to $119.9 M, versus $115.1 M for the baseline. The 3-axis scenario increases in cost by $13.2 M to $130.5 M, versus $138.8 M for the baseline.

The conclusion is that without insurance benefits the spinner scenario is definitely not viable. The 3-axis scenario continues to show benefits, although reduced greatly from $21.5 M to $8.5 M. Table VIII-4 summarizes the satellite cost and rate-of-return (DTRR) changes for the 3-axis scenario with 20% insurance rate.

5.3 Launch Costs

Table VIII-5 summarizes the effects of some substantial changes in launch charges on system costs. The baseline and 3-axis scenario costs are compared for each launch cost assumption. The scenario continues to show value regardless of the launch cost change. The economics are very sensitive to changes in OTV costs. The assumption of STS charges being reduced by 50% also has a large negative effect on scenario economics.

Cost Change	Cost ($M 1985) Baseline	Scenario	Delta
Original case	138.8	117.3	21.5
OTV plus 50%	138.8	127.7	11.1
STS minus 50%	116.7	108.3	8.4
OTV minus 50%	138.8	106.9	31.9
STS/OTV -50%	116.7	97.9	18.8

Table VIII–5: Influence of Launch Costs

5.4 Use of Mass Savings to Increase Payload

The methodology for determining APO economic value as set forth in Subsection VII-2 states that the "satellite payload is not altered" in response to satellite mass changes due to the APOs. The reasons behind this assumption are as follows:

- The mass changes involved are relatively small, ±40 kg, and fall within the mass margin of the satellite.
- Since the capacity of the OTV (contrary to conventional upper stages) is much larger than the mass of a single satellite, there is no upper limit on how much the payload can be increased.
- There is a problem in how to use the mass savings to enhance the payload. More transponders may imply more antennas. Alternately, more power could be supplied to each transponder or smaller bandwidth transponders could be used. The result is a specialized payload to exploit the APO scenario.

The spinner and 3-axis satellite designs used in the scenarios are described in Tables IV-7 and IV-10 respectively. The satellite mass changes for the combination APOs used in the scenarios are +41.9 kg for the spinner (Table VI-1) and -31 kg for the 3-axis (Table VI-2). The effect on economic performance of using the 31 kg mass saved by the 3-axis scenario to increase the satellite payload will be calculated.

The 31 kg of mass corresponds to the addition of two more Ku-band transponders, taking into account the mass increase of the power and thermal subsystems as well as the payload. Using the Price H model, the satellite cost increased from $62.47 M to $65.8 M for the 3-axis scenario. It is assumed that the two added transponders are the same as the existing 33 W, 36 MHz bandwidth Ku-band transponders.

The Financial Model is used to calculate the economic performance of the enhanced satellite. The result is a 23.4% rate-of-return (DTRR) versus the baseline scenario 23.3% return. This is an insignificant improvement, but analysis has been based on a relatively crude analysis. It does point out, however, that use of the OTV APO may have more value than is reported by this study.

6 Conclusions

The spinner scenario has a small nominal value with the hypothesized costs, but is sensitive to changes in insurance and launch costs. This scenario is judged to be not economically viable.

The 3-axis scenario shows substantial value which continues to be positive under worst case insurance and launch cost assumptions. This scenario is judged to be economically viable.

The assembly/servicing scenario has equal value to two successive launches of the 3-axis scenario. Considering our relatively crude analysis of the satellite design, we believe this scenario has promise of better performance and should be analyzed in more detail.

Section IX
SPACE STATION REQUIREMENTS

1 Introduction

This section presents the Task 4 results on the functional and technical requirements imposed on the Space Station by the implementation of the scenarios of Section VIII. The requirements are presented in the following categories:

- Space Station hardware requirements
- OMV requirements
- OTV requirements
- Operations and policy

2 Space Station Requirements

Space Station hardware requirements are discussed for the following items:

- Servicing and storage bay
- Automated transfer facilities
- Fueling facilities

2.1 Servicing and Storage Bay

The primary requirement on the Space Station is the inclusion of a servicing/storage bay in the IOC design. An early servicing bay would be used for unscheduled retrieval missions where a perigee motor or ELV upper stage fails, leaving the satellite in an orbit not accessible to the OMV.

The economic and environmental advantages of retrieval missions to the Space Station justify the initial inclusion of this area. The servicing/storage bay would later be used for storage of satellites prior to using the OTV and for storing and assembling small satellites.

The storage bay should be large enough to accommodate up to four 1995 satellite designs for storage and an additional area for servicing. A 10 m x 10 m x 20 m volume should be sufficient. The bay should be enclosed for micrometeorite and passive thermal protection which can be augmented by internal satellite thermal systems. In addition, standard power and communications ports should be available so that satellites can use Space Station power and can be monitored from inside the manned modules. Power consumption is expected to be in the range of 10 W to 400 W per satellite and data rates are low (1200 b/s).

The servicing/storage bay should be located near the OTV facility and other transportation nodes for the Shuttle and OMV. Since the mobile remote manipulator system (MRMS) used for satellite transfer moves slowly, the time of transfer becomes a concern for the power, thermal, and telemetry systems. Increasing satellite batteries for this procedure should be avoided. Another issue is the torque noise during satellite transfer, which may affect other operations requiring a stable environment. (Torque noise is mechanical vibration and oscillation caused by use of the MRMS.)

2.2 Automated Transfer Facilities

A universal retention system should be developed to reduce the required hardware weight on satellite systems, and allow automated docking and release.

Automated systems such as the MRMS (mobile remote manipulator system) are needed to transfer satellites and equipment to and from the Shuttle, OTV, OMV, and storage/servicing bay. Systems with a high level of articulation and control are desired to reduce demand for EVA activity such as deployments and connections.

2.3 Fueling Facilities

Fueling facilities may be required at the Space Station. Although there is no economic advantage for fueling at the Space Station, other factors such as Shuttle launch safety may require it, as may APOs such as assembly. The issues surrounding fueling should be examined in depth before placing requirements on the Space Station.

3 OMV Requirements

The initial use of the OMV is as a space tug to retrieve stranded satellites from LEO as well as transfer cargo from ELVs to the Space Station. This requires space-basing of an OMV in order to be available for unscheduled events such as emergency retrieval.

The OMV would need to be attachable to a servicing device such as the Smart Front End for GEO servicing. This combination should have the capability of servicing several satellites on each mission. Methods for changing out modules should be standardized and tested in LEO prior to use in GEO.

There should be at least two OMVs in order to be able to retrieve a malfunctioning OMV to the Space Station for repair.

4 OTV Requirements

The OTV offers the largest economic advantage of the APOs evaluated in Section VII. The requirements placed on the OTV by this study are within the scope of the capabilities required by the initial OTV studies. Several satellites must be launched at once in order for the relatively large capacity OTV to be economical. This requires a multiple payload carrier (MPC) which should use a standard retention system compatible with the Space Station servicing bay.

The OTV should provide power and telemetry links to the satellite while in transit. Slow spinning of the OTV will assist in maintaining the thermal environment of the satellites.

The OTV should be capable of maintaining accelerations of 0.1 G or less to allow appendage deployment at the Space Station. This feature would also be required for large communications antennas and platforms not covered in this study.

There should be at least two OTVs in order to be able to retrieve a malfunctioning OTV to the Space Station for repair. An OTV based at the Space Station is preferred to the ground-based alternative in order to respond more rapidly to an emergency retrieval.

5 Operations and Policy

There are other requirements that the satellite communications industry places on the Space Station infrastructure beyond hardware or scarring needs. It is important that scheduled use of the Space Station, OMV, or OTV not be interrupted. Many of the APOs using the Space Station will have no alternative if the service is delayed due to higher priority government missions. The Space Station should adopt a set of operations and policies that insure its users a high degree of reliability.

The procedures required on the ground for Space Station safety should become streamlined without hindering the determination of safeness. Present NASA safety requirements for the Shuttle require a large amount of paperwork and additional test time prior to launch. The safety requirements for the Station should be studied far in advance so that an efficient safety regulation program can be utilized.

Space Station policies should be devised so that termination of services will not occur without sufficient lead time to allow satellite manufacturers to phase Space Station APOs out of their designs. Reduction of services due to safety or accidents should not be placed only on the commercial users.

6 Summary of Requirements

The requirements on the Space Station and its associated equipment are summarized in the following subsections:

1. Spinner and 3-axis scenario requirements
2. Assembly/servicing scenario requirements
3. LEO retrieval/repair scenario requirements

6.1 Spinner/3-axis Scenarios

Provide Storage Area for Satellites

- Provide satellite storage area for 4 satellites.
- Physical protection from contamination, meteorites, etc.
- All areas accessible to MRMS and EVA.
- Standard retention systems for satellites.
- Provide standard volt dc power to satellites; tbd (to be determined) W.
- Telemetry data links for thermal and health checks.

Provide Servicing Area for Satellites

- Standard NASA tools available with back-ups.
- Proximity to storage area to facilitate transport.
- Physical protection from contamination, meteorites, etc.
- Accessible to MRMS, full RMS capability at assembly site.
- Standard retention systems for satellites.
- Provide standard volt dc power to satellites; tbd W.
- Telemetry data links for satellite checks.

Provide Fueling Capability

- Low cost propellants and pressurants available.
- Storage areas for propellants, pressurants.
- Fueling quick disconnects.
- Simultaneous fueling of bipropellants, pressurant.
- To be determined flow rate for propellants.
- Automatic emergency shutdown of fueling system.
- Telemetry data link for satellite check, fueling data.

Provide Checkout Facilities for Satellites

- Monitor electrical and physical parameters of satellite.
- Connect OTV to MPC while docked.
- Telemetry links to all satellite stations.
- Equipment for monitoring, trouble shooting, and analysis.

Provide MRMS with Satellite Handling Capability

- Accessible to all satellite areas.
- Standard grapple fixtures.
- Smooth, automatic transfer of satellite.

Provide Deployment Capability for Satellites on OTV

Provide Space-Based OTV

- Low thrust capability, 0.1 G.
- Multiple payload carrier (MPC) with standard volt dc power.
- Slow spin capability for thermal control of satellites.

6.2 Assembly/Servicing Scenario

Assembly Requirements

- Requirements as listed for 3-axis satellite scenario.
- Storage for unassembled modules with thermal control.

- Provide standard tools for satellite assembly.
- Advanced checkout capabilities.

Servicing Requirements

- "Smart" servicer capable of replacing snap-on modules.
- On-orbit fueling capability.
- Multiple mission capability in order to service several satellites during one trip to GEO.

6.3 LEO Retrieval/Repair Scenario Requirements

- OMV based at Station with quick reaction (1 day) for emergency retrieval (standardized retrieval system with minimum impact on satellite design).
- Storage/servicing area with passive thermal control and micrometeorite protection.
- Standard volt dc power supply outlet for satellite, tbd W.
- Standardized communications port to determine satellite health and monitor thermal status.
- Provide EVA capability to attempt minor satellite repair in servicing bay.

Section X
RECOMMENDATIONS

1 Introduction

This section presents the recommendations of the study on the following issues:

- Desirability of space-based OTV
- Study of retrieval missions
- Study of modular satellite design
- Technology development
- Purpose of Space Station

2 Need for Space-Based OTV

The space-based OTV is recommended rather than a ground-based OTV for several reasons. Most important is minimization of possible scheduling problems. Operations based at the Space Station such as deployment and assembly would need to be scheduled simultaneously with the ground launch of the ground-based OTV. Delays occurring on the ground (for example, due to weather) could disrupt schedules at the Station due the necessity for preparing and protecting multiple satellite. Conversely, satellite operation delays at the Station could delay the ground launch. The ground-based OTV, if fueled, requires a large amount of power to prevent cryogenic boil-off losses.

Another reason for recommending a space-based OTV is risk. Requiring a ground launch for every OTV launch adds risk to the system which could affect the insurance advantage associated with the OTV.

A concern raised by this study is the operational aspect of interfacing a ground-based OTV with the Station and a return vehicle such as the Shuttle. The logistics and cost of returning, refurbishing, and relaunching an OTV have not been determined. A fueling system of a space-based OTV could possibly be simplified by using ground launched tanks that could be "snapped" into the OTV in space. This concept could decrease the cost of launching and retrieving the entire OTV, and may be more cost effective than scavenging systems with long term space-based fueling depots.

The final OTV issue is the cost comparison between space-based and ground-based operation. The obvious advantage of space-basing is that the OTV structure does not need to be carried from Earth to LEO for each mission. As shown in the sensitivity analysis of Subsection VIII-5 and discussion of launch costs in Subsection VII-2.3, economics are very sensitive to launch cost assumptions. Perhaps future reduction in launch costs will make this point academic. A careful analysis of OTV costs is needed.

The feasibility of many APOs may be impacted adversely by use a ground-based OTV due to operational constraints.

3 Study of Retrieval Missions

The economics of retrieval missions is discussed in Subsection VII-5. There can be substantial benefits in retrieval missions and we see this to be a natural function of the Space Station from its position as a "gateway to space" and transportation node.

We recommend that NASA sponsor a study of the economics of retrieval missions and the influence of retrieval on the insurance industry. The goals of this study would be to more accurately demonstrate the value of retrievability for the satellite and to more closely define the operational aspects of retrievability on the Space Station and the satellite.

Involvement of insurance company representatives in the study is desirable, along with a methodology to assess financial risk (defined as the standard deviation in the rate-of-return) for different retrieval scenarios.

4 Study of Modular Satellite Design

A modular satellite design is required for implementation of assembly and servicing scenarios. We recommend that NASA sponsor a study in this area in order to stimulate the satellite manufacturing industry to consider these designs.

A future NASA or government satellite should then incorporate a requirement for serviceability and/or assembly in order to demonstrate feasibility.

5 Study of ELV Use

NASA has recently said that commercial launches will be phased out of the Shuttle program. Expendable Launch Vehicles (ELVs) will need to be used for transport from Earth to LEO (near the Space Station), instead of using the Shuttle as assumed in this study. There are potential impacts on launch costs and risks, on the APOs, and on the requirements placed on the ELV system.

A study is needed to determine the effect that launching commercial communications satellites to LEO on ELVs would have on the APOs, and the requirements placed on the ELVs. The ELV system needs to be designed to supply regular and reliable transportation form Earth to Space Station in order to facilitate the APOs.

6 Technology Developments

The following technology developments are recommended:

- Modular satellite designs
- OTV with low thrust and based in space
- RF interfaces for assemblable satellite
- Telerobotics for IVA operations and servicing

7 Purpose of Space Station

We see the highest use of the first Space Station as a transportation node with associated staging and assembly areas. Some requirements like safety are of continuing concern, but the inappropriate placing of instruments or experiments on the initial Station that place further difficult requirements is to be avoided.

The value of the Space Station as transportation node will vanish if it is too difficult to use. The commercial sector will not use something that places addition financial risks on the operations, such as time delays in on-orbit operation. For instance, a one month delay in IOC is equivalent to 0.4% rate-of-return (DTRR) or \$5 M initial cost.

NASA Contract No. NAS3-24253

COMMUNICATIONS SATELLITE SYSTEMS OPERATIONS WITH THE SPACE STATION

APPENDICES for TECHNICAL REPORT

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LIST of TABLES

LIST of TABLES (Continued)

Appendix A

FINANCIAL MODEL OUTPUT 1985 SATELLITE SYSTEMS

This appendix contains the Financial Model results for the three 1985 satellite designs described in Section II:

1. C-band, spinner satellite (Table II-2)
2. Ku-band, 3-axis satellite (Table II-3)
3. Hybrid (C and Ku-bands), 3-axis satellite (Table II-4)

These results are discussed in Subsection II-5, and consist of nine pages of output for each satellite system.

The output pages for each satellite contain the following information which is described in Subsection II-4.5.1:

- Page 1: Financial analysis
- Page 2: Income statement (cash basis)
- Page 3: Balance sheet (cash basis)
- Page 4: Sources and uses of funds statement
- Page 5: Revenue assumptions (three separate pages for C-band, Ku-band, and Other transponders)
- Page 6: Capital expenditure and general assumptions
- Page 7: Operating expenditure assumptions
- Page 8: Financing assumptions
- Page 9: Tax assumptions

The tables are numbered A-1.1, A-1.2, ... A-1.9 for the C-band system, Table A-2.1 etc. for the Ku-band system, and Table A-3.1 etc. for the hybrid satellite system.

The bottom line "result" is the dual terminal rate of return which is presented on page 1. Pages 5a, b, c show the revenues from lease of the transponders. Page 6 shows the breakdown of costs for the satellite.

POOR QUALITY

Run Date: 17-Jun-86

FINANCIAL ANALYSIS

DUAL TERMINAL RATE OF RETURN		INTERNAL RATE OF RETURN		NET PRESENT VALUE	
Required Return on Equity (Projected Reinvestment Rate)	18.00%	Internal Rate of Return	18.15%	Projected Cost of Equity (Discount Rate)	18.00%
Dual Terminal Rate of Return	18.06%			Net Present Value	211,216

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Net Income (Loss)	(1.50)	(2.27)	(2.88)	10.02	1.61	2.44	2.97	3.55	12.08	11.61	11.35	11.11	10.92	0.00	0.00
Plus: Tax Depreciation	0.00	0.00	0.00	11.48	16.83	16.07	16.07	16.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Less: Principal Payments	0.00	0.00	0.00	5.47	6.10	6.80	7.60	8.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Flow From Operations	(1.50)	(2.27)	(2.88)	16.03	12.34	11.71	11.44	11.15	12.08	11.61	11.35	11.11	10.92	0.00	0.00
Equity Investment:															
Fund Cash Deficit	1.50	2.27	2.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fund Fixed Asset Additions	10.31	13.79	14.55	3.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Equity Cash Flows	(11.81)	(16.06)	(17.43)	12.60	12.34	11.71	11.44	11.15	12.08	11.61	11.35	11.11	10.92	0.00	0.00
Dual Terminal Cash Flows	(37.94)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	278.29	0.00	0.00

Table A-1.1: Financial Analysis (1985 C-band Satellite System)

Run Date: 17-Jun-86

INCOME STATEMENT (CASH BASIS)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Project Revenues	0.00	0.00	0.00	32.43	32.43	32.43	32.43	32.43	32.43	31.03	29.94	28.84	27.75	0.00	0.00
Operating Expenses:															
TT&C	0.00	0.00	0.00	1.29	1.30	1.31	1.33	1.34	1.35	1.37	1.38	1.39	1.41	0.00	0.00
Life Insurance	0.00	0.00	0.00	5.72	5.45	5.13	4.76	4.32	3.80	3.19	2.52	1.77	0.94	0.00	0.00
Operations & Maintenance	0.00	0.00	0.00	0.52	0.54	0.56	0.58	0.61	0.63	0.66	0.68	0.71	0.74	0.00	0.00
Operating Income	0.00	0.00	0.00	24.90	25.14	25.43	25.76	26.16	26.65	25.81	25.36	24.97	24.66	0.00	0.00
Selling, General & Administrative:															
Sales & Marketing:															
Pre-operational	1.53	1.59	1.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	0.57	0.59	0.62	0.64	0.67	0.70	0.72	0.72	0.71	0.70	0.00	0.00
General & Administrative:															
Pre-operational	0.92	0.96	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	1.56	1.62	1.69	1.75	1.82	1.90	1.97	2.05	2.13	2.22	0.00	0.00
Depreciation	0.00	0.00	0.00	11.48	16.83	16.07	16.07	16.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Income Before Interest & Taxes	(2.45)	(2.55)	(2.65)	11.29	6.10	7.05	7.30	7.60	24.05	23.12	22.59	22.13	21.74	0.00	0.00
Interest Expense	0.54	1.97	3.09	3.52	2.89	2.19	1.39	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earnings Before Tax	(2.99)	(4.52)	(5.74)	7.77	3.21	4.86	5.91	7.08	24.05	23.12	22.59	22.13	21.74	0.00	0.00
Federal & State Tax	(1.49)	(2.25)	(2.86)	(2.25)	1.60	2.42	2.94	3.53	11.97	11.51	11.24	11.02	10.82	0.00	0.00
Net Income (Loss)	(1.50)	(2.27)	(2.88)	10.02	1.61	2.44	2.97	3.55	12.08	11.61	11.35	11.11	10.92	0.00	0.00

Table A-1.2: Income Statement (1985 C-band Satellite System)

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Run Date: 17-Jun-86 BALANCE SHEET (CASH BASIS) Page 3

Assets	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash	0.00	0.00	0.00	16.03	28.37	40.08	51.52	62.67	74.75	86.36	97.71	108.82	119.74	119.74	119.74
Fixed Assets	18.75	43.83	70.28	76.52	76.52	76.52	76.52	76.52	76.52	76.52	76.52	76.52	76.52	76.52	76.52
Accumulated Dep.	0.00	0.00	0.00	11.48	28.31	44.38	60.45	76.52	76.52	76.52	76.52	76.52	76.52	76.52	76.52
Total Assets	18.75	43.83	70.28	81.07	76.58	72.22	67.59	62.67	74.75	86.36	97.71	108.82	119.74	119.74	119.74
Liabilities & Equity															
Construction Loan	8.44	19.73	31.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Permanent Loan	0.00	0.00	0.00	28.97	22.87	16.07	8.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Liabilities	8.44	19.73	31.63	28.97	22.87	16.07	8.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity	11.81	27.87	45.30	48.73	48.73	48.73	48.73	48.73	48.73	48.73	48.73	48.73	48.73	48.73	48.73
Retained Earnings	(1.50)	(3.77)	(6.65)	3.37	4.98	7.42	10.39	13.94	26.02	37.63	48.98	60.09	71.01	71.01	71.01
Total equity	10.31	24.10	38.65	52.10	53.71	56.15	59.12	62.67	74.75	86.36	97.71	108.82	119.74	119.74	119.74
Total Liab. & Equity	18.75	43.83	70.28	81.07	76.58	72.22	67.59	62.67	74.75	86.36	97.71	108.82	119.74	119.74	119.74

Table A-1.3: Balance Sheet (1985 C-band Satellite System)

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Run Date: 17-Jun-86

SOURCES & USES OF FUNDS STATEMENT

Page 4

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash Balance Beg. Year	0.00	0.00	0.00	0.00	16.03	28.37	40.08	51.52	62.67	74.75	86.36	97.71	108.82	119.74	119.74
Sources of Funds:															
Net Income (Less Depreciation)	0.00	0.00	0.00	21.50	18.44	18.51	19.04	19.62	12.08	11.61	11.35	11.11	10.92	0.00	0.00
Increase in Construction Debt	8.44	11.29	11.90	2.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Increase in Permanent Debt	0.00	0.00	0.00	34.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity Investment	11.81	16.06	17.43	3.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Sources of Funds	20.25	27.35	29.33	62.18	18.44	18.51	19.04	19.62	12.08	11.61	11.35	11.11	10.92	0.00	0.00
Uses of Funds:															
Net Loss (Less Depreciation)	1.50	2.27	2.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fixed Assets Additions	18.75	25.08	26.45	6.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Construction Debt	0.00	0.00	0.00	34.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Permanent Debt	0.00	0.00	0.00	5.47	6.10	6.80	7.60	8.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Uses of Funds	20.25	27.35	29.33	46.15	6.10	6.80	7.60	8.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Balance End Year	0.00	0.00	0.00	16.03	28.37	40.08	51.52	62.67	74.75	86.36	97.71	108.82	119.74	119.74	119.74

Table A-1.4: Sources and Uses of Funds Statement (1985 C-band Satellite System)

Run Date: 03-Jun-86

REVENUE ASSUMPTIONS -- C-BAND

Number of Transponders:	
Protected	18
Unprotected	4
Preemptable	2
Mkt. Price/Basic Transponder:	
Protected	$1.90
Unprotected	$1.40
Preemptable	$0.90
Inflation Factors:	
Protected	0.00%
Unprotected	0.00%
Preemptable	0.00%

Utilization Factor	90.00%
Frequency (C-Band)	1
Bandwidth	36 MHz
Transponder Power	5.5 Watts
Degradation Curve (1=C-band, 2=Ku-Band, 3=Hybrid, 4=Other)	1

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Unprotected	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Preemptable	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.85	0.80	0.80	0.00
Operating Transponders:															
Protected	18	18	18	18	18	18	18	18	18	18	18	18	18	0	0
Unprotected	4	4	4	4	4	4	4	4	4	4	3	2	1	0	0
Preemptable	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90
Unprotected	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40
Preemptable	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Marketing Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Band Width Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Power Factor	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Total Revenues	$0.00	$0.00	$0.00	$32.43	$32.43	$32.43	$32.43	$32.43	$32.43	$31.03	$29.94	$28.84	$27.75	$0.00	$0.00

Table A-1.5a: Revenue Assumptions – C-band Transponders (1985 C-band Satellite System)

Run Date: 17-Jun-86

CAPITAL EXPENDITURE AND GENERAL ASSUMPTIONS

Capital Expenditures	Total ($)	Payment Schedule Year 1	Year 2	Year 3	Year 4
Satellite Cost	38.23	28.54%	40.45%	21.01%	10.00%
STS Launch Cost	17.19	17.63%	31.53%	50.84%	0.00%
Perigee Stage Cost	6.21	28.54%	40.45%	21.01%	10.00%
Launch Support Cost	1.64	28.54%	40.45%	21.01%	10.00%
Mission Operations	2.55	28.54%	40.45%	21.01%	10.00%
Launch Insurance	10.71	17.14%	0.00%	70.00%	12.86%
OMV/OTV Cost	0.00	0.00%	0.00%	0.00%	0.00%
Space Station Support Cost	0.00	0.00%	0.00%	0.00%	0.00%

Capital Expenditures	Total	Year 1	Year 2	Year 3	Year 4
Satellite Cost	38.22	10.91	15.46	8.03	3.82
STS Launch Cost	17.19	3.03	5.42	8.74	0.00
Perigee Stage Cost	6.20	1.77	2.51	1.30	0.62
Launch Support Cost	1.63	0.47	0.66	0.34	0.16
Mission Operations	2.56	0.73	1.03	0.54	0.26
Launch Insurance	10.72	1.84	0.00	7.50	1.38
OMV/OTV Cost	0.00	0.00	0.00	0.00	0.00
Space Station Support Cost	0.00	0.00	0.00	0.00	0.00
Total Capital Expenditures	76.52	18.75	25.08	26.45	6.24

General Assumptions

General Assumptions	
Project Starting Year (1985 is base year)	-2
Month Placed in Service	36
Useful Life (in months)	120

The satellite, perigee, launch support, and mission operations costs include a 12% allocation for manufacturer G&A and a 12% fee.

Launch insurance is estimated to cost 14% of total capital cost of the satellite, STS launch, perigee stage, launch support, mission operations and launch insurance.

Table A-1.6: Capital Expenditure and General Assumptions (1985 C-band Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

Run Date: 03-Jun-86

OPERATING EXPENDITURE ASSUMPTIONS

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	Base Amount	Infla %
Annual TT&C	1.275	1.00%
Annual Life Insurance (% of NPV of Revenues)	4.00%	N/A
Annual Operations & Maintenance	0.500	4.00%
Annual Sales & Marketing:		
Pre-operational (per Transponder)	0.075	4.00%
Post-operational (per Transponder)	0.025	4.00%
Annual General & Administrative:		
Pre-operational	1.000	4.00%
Post-operational	1.500	4.00%
Discount Factor for Life Insurance (Assumed Cost of Equity)	18.00%	

TT&C cost includes both fixed and variable components; only the variable component is subject to inflation. This results in an effective inflation rate of approximately 1% of the gross amount.

Table A-1.7: Operating Expenditure Assumptions (1985 C-band Satellite System)

Run Date: 17-Jun-86

FINANCING ASSUMPTIONS

% of Capital Expenditures Funded With Debt	45.00%		
Construction Loan Terms:	Year 1	Year 2	Year 3
Interest Rate	12.81%	13.97%	12.04%
Permanent Loan Terms:			
Loan Principal (In Millions)	34.44		
Term of Loan (Months)	60		
Month of First Payment	1		
Year of First Payment	4		
Annual Interest Rate	11.00%		
Monthly Payment (Automatic)	0.75		

Interest expense is projected, including all transaction costs, to average prime plus 2 percentage points. The prime rate average for 1983 was 10.81% and was 11.97% for 1984. For the first nine months of 1985, the prime rate average was 10.04%. The 1986 first quarter prime rate avg. is 9.00% .

Year	Months Remaining	Year End Balance	Principal	Interest
1	0	0.00	0.00	0.00
2	0	0.00	0.00	0.00
3	0	0.00	0.00	0.00
4	48	28.97	5.47	3.52
5	36	22.87	6.10	2.89
6	24	16.07	6.80	2.19
7	12	8.47	7.60	1.39
8	0	0.00	8.47	0.52
9	0	0.00	0.00	0.00
10	0	0.00	0.00	0.00
11	0	0.00	0.00	0.00
12	0	0.00	0.00	0.00
13	0	0.00	0.00	0.00
14	0	0.00	0.00	0.00
15	0	0.00	0.00	0.00

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Table A-1.8: Financing Assumptions (1985 C-band Satellite System)

Run Date: 17-Jun-86

TAX ASSUMPTIONS

Tax Rates:

Marginal Federal Rate	46.00%
Marginal State Rate	7.00%
Investment Tax Credit Rate	8.00%
Depreciation Method	ACRS
Satellite Life (For Tax Purposes)	5 Years

The combined Federal & State tax rates result in a 49.78% effective tax rate.

Federal & State Tax Computation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Earnings Before Tax	(2.99)	(4.52)	(5.74)	7.77	3.21	4.86	5.91	7.08	24.05	23.12	22.59	22.13	21.74	0.00	0.00
State Tax	(0.21)	(0.32)	(0.40)	0.54	0.22	0.34	0.41	0.50	1.68	1.62	1.58	1.55	1.52	0.00	0.00
Federal Taxable Income	(2.78)	(4.20)	(5.34)	7.23	2.99	4.52	5.50	6.58	22.37	21.50	21.01	20.58	20.22	0.00	0.00
Federal Tax	(1.28)	(1.93)	(2.46)	3.33	1.38	2.08	2.53	3.03	10.29	9.89	9.66	9.47	9.30	0.00	0.00
Investment Tax Credit	0.00	0.00	0.00	(6.12)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Tax Cost (Benefit)	(1.49)	(2.25)	(2.86)	(2.25)	1.60	2.42	2.94	3.53	11.97	11.51	11.24	11.02	10.82	0.00	0.00

Table A-1.9: Tax Assumptions (1985 C-band Satellite System)

ORIGINAL PAGE IS
OF POOR QUALITY

Run Date: 17-Jun-86

FINANCIAL ANALYSIS

Page 1

DUAL TERMINAL RATE OF RETURN		INTERNAL RATE OF RETURN		NET PRESENT VALUE	
Required Return on Equity (Projected Reinvestment Rate)	18.00%	Internal Rate of Return	22.57%	Projected Cost of Equity (Discount Rate)	18.00%
Dual Terminal Rate of Return	19.83%			Net Present Value	8,562,152

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Net Income (Loss)	(1.32)	(2.32)	(3.14)	16.48	5.07	6.29	7.07	7.20	18.11	16.85	17.25	16.09	16.57	0.00	0.00
Plus: Tax Depreciation	0.00	0.00	0.00	15.64	22.94	21.89	21.89	21.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Less: Principal Payments	0.00	0.00	0.00	7.45	8.31	9.27	10.35	11.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Flow From Operations	(1.32)	(2.32)	(3.14)	24.67	19.70	18.91	18.61	17.55	18.11	16.85	17.25	16.09	16.57	0.00	0.00
Equity Investment:															
Fund Cash Deficit	1.32	2.32	3.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fund Fixed Asset Additions	13.85	18.63	20.35	4.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Equity Cash Flows	(15.17)	(20.95)	(23.49)	20.17	19.70	18.91	18.61	17.55	18.11	16.85	17.25	16.09	16.57	0.00	0.00
Dual Terminal Cash Flows	(49.79)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	436.52	0.00	0.00

Table A-2.1: Financial Analysis (1985 Ku-band Satellite System)

Run Date: 17-Jun-86

INCOME STATEMENT (CASH BASIS)

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Project Revenues	0.00	0.00	0.00	48.75	48.75	48.75	48.75	47.21	45.66	42.40	42.40	39.14	39.14	0.00	0.00
Operating Expenses:															
TT&C	0.00	0.00	0.00	1.29	1.30	1.31	1.33	1.34	1.35	1.37	1.38	1.39	1.41	0.00	0.00
Life Insurance	0.00	0.00	0.00	8.38	7.94	7.42	6.81	6.08	5.29	4.42	3.51	2.45	1.33	0.00	0.00
Operations & Maintenance	0.00	0.00	0.00	0.52	0.54	0.56	0.58	0.61	0.63	0.66	0.68	0.71	0.74	0.00	0.00
Operating Income	0.00	0.00	0.00	38.56	38.97	39.46	40.03	39.18	38.39	35.95	36.83	34.59	35.66	0.00	0.00
Selling, General & Administrative:															
Sales & Marketing:															
Pre-operational	0.97	1.01	1.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	0.36	0.38	0.39	0.41	0.43	0.44	0.43	0.44	0.43	0.44	0.00	0.00
General & Administrative:															
Pre-operational	0.92	0.96	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	1.56	1.62	1.69	1.75	1.82	1.90	1.97	2.05	2.13	2.22	0.00	0.00
Depreciation	0.00	0.00	0.00	15.64	22.94	21.89	21.89	21.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Income Before Interest & Taxes	(1.89)	(1.97)	(2.05)	21.00	14.03	15.49	15.98	15.04	36.05	33.55	34.34	32.03	33.00	0.00	0.00
Interest Expense	0.73	2.65	4.20	4.79	3.93	2.97	1.89	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earnings Before Tax	(2.62)	(4.62)	(6.25)	16.21	10.10	12.52	14.09	14.34	36.05	33.55	34.34	32.03	33.00	0.00	0.00
Federal & State Tax	(1.30)	(2.30)	(3.11)	(0.27)	5.03	6.23	7.02	7.14	17.94	16.70	17.09	15.94	16.43	0.00	0.00
Net Income (Loss)	(1.32)	(2.32)	(3.14)	16.48	5.07	6.29	7.07	7.20	18.11	16.85	17.25	16.09	16.57	0.00	0.00

Table A-2.2: Income Statement (1985 Ku-band Satellite System)

ORIGINAL PAGE IS
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Run Date: 17-Jun-86

BALANCE SHEET (CASH BASIS)

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Assets	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash	0.00	0.00	0.00	24.67	44.37	63.28	81.89	99.44	117.55	134.40	151.65	167.74	184.31	184.31	184.31
Fixed Assets	25.18	59.06	96.06	104.25	104.25	104.25	104.25	104.25	104.25	104.25	104.25	104.25	104.25	104.25	104.25
Accumulated Dep.	0.00	0.00	0.00	15.64	38.58	60.47	82.36	104.25	104.25	104.25	104.25	104.25	104.25	104.25	104.25
Total Assets	25.18	59.06	96.06	113.28	110.04	107.06	103.78	99.44	117.55	134.40	151.65	167.74	184.31	184.31	184.31
Liabilities & Equity															
Construction Loan	11.33	26.58	43.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Permanent Loan	0.00	0.00	0.00	39.47	31.16	21.89	11.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Liabilities	11.33	26.58	43.23	39.47	31.16	21.89	11.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity	15.17	36.11	59.61	64.11	64.11	64.11	64.11	64.11	64.11	64.11	64.11	64.11	64.11	64.11	64.11
Retained Earnings	(1.32)	(3.63)	(6.78)	9.70	14.77	21.06	28.13	35.33	53.44	70.29	87.54	103.63	120.20	120.20	120.20
Total equity	13.85	32.48	52.83	73.81	78.88	85.17	92.24	99.44	117.55	134.40	151.65	167.74	184.31	184.31	184.31
Total Liab. & Equity	25.18	59.06	96.06	113.28	110.04	107.06	103.78	99.44	117.55	134.40	151.65	167.74	184.31	184.31	184.31

Table A-2.3: Balance Sheet (1985 Ku-band Satellite System)

Run Date: 17-Jun-86

SOURCES & USES OF FUNDS STATEMENT

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash Balance Beg. Year	0.00	0.00	0.00	0.00	24.67	44.37	63.28	81.89	99.44	117.55	134.40	151.65	167.74	184.31	184.31
Sources of Funds:															
Net Income (Less Depreciation)	0.00	0.00	0.00	32.12	28.01	28.18	28.96	29.09	18.11	16.85	17.25	16.09	16.57	0.00	0.00
Increase in Construction Debt	11.33	15.25	16.65	3.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Increase in Permanent Debt	0.00	0.00	0.00	46.92	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity Investment	15.17	20.95	23.49	4.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Sources of Funds	26.50	36.20	40.14	87.23	28.01	28.18	28.96	29.09	18.11	16.85	17.25	16.09	16.57	0.00	0.00
Uses of Funds:															
Net Loss (Less Depreciation)	1.32	2.32	3.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fixed Assets Additions	25.18	33.88	37.00	8.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Construction Debt	0.00	0.00	0.00	46.92	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Permanent Debt	0.00	0.00	0.00	7.45	8.31	9.27	10.35	11.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Uses of Funds	26.50	36.20	40.14	62.56	8.31	9.27	10.35	11.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Balance End Year	0.00	0.00	0.00	24.67	44.37	63.28	81.89	99.44	117.55	134.40	151.65	167.74	184.31	184.31	184.31

Table A-2.4: Sources and Uses of Funds Statement (1985 Ku-band Satellite System)

ORIGINAL PAGE IS
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Run Date: 03-Jun-86

REVENUE ASSUMPTIONS -- Ku-BAND

Number of Transponders:		Utilization Factor	90.00%
Protected	14		
Unprotected	0		
Preemptable	2	Frequency (Ku-Band)	2
Mkt. Price/Basic Transponder:			
Protected	$1.90	Bandwidth	54 MHz
Unprotected	$1.40		
Preemptable	$0.90		
		Transponder Power	50.0 Watts
Inflation Factors:			
Protected	0.00%		
Unprotected	0.00%	Degradation Curve (1=C-Band, 2=Ku-band, 3=Hybrid, 4=Other)	2
Preemptable	0.00%		

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.90	0.87	0.85	0.78	0.75	0.70	0.00
Operating Transponders:															
Protected	14	14	14	14	14	14	14	14	14	13	13	12	12	0	0
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	2	2	2	2	2	2	2	1	0	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90
Unprotected	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40
Preemptable	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Marketing Factor	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Band Width Factor	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Power Factor	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
Total Revenues	$0.00	$0.00	$0.00	$48.75	$48.75	$48.75	$48.75	$47.21	$45.66	$42.40	$42.40	$39.14	$39.14	$0.00	$0.00

Table A-2.5b: Revenue Assumptions -- Ku-band Transponders (1985 Ku-band Satellite System)

Run Date: 17-Jun-86

CAPITAL EXPENDITURE AND GENERAL ASSUMPTIONS

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Capital Expenditures	Total ($)	Payment Schedule Year 1	Year 2	Year 3	Year 4
Satellite Cost	48.17	28.54%	40.45%	21.01%	10.00%
STS Launch Cost	26.63	17.63%	31.53%	50.84%	0.00%
Perigee Stage Cost	10.66	28.54%	40.45%	21.01%	10.00%
Launch Support Cost	1.64	28.54%	40.45%	21.01%	10.00%
Mission Operations	2.55	28.54%	40.45%	21.01%	10.00%
Launch Insurance	14.59	17.14%	0.00%	70.00%	12.86%
OMV/OTV Cost	0.00	0.00%	0.00%	0.00%	0.00%
Space Station Support Cost	0.00	0.00%	0.00%	0.00%	0.00%

Capital Expenditures	Total	Year 1	Year 2	Year 3	Year 4
Satellite Cost	48.17	13.75	19.48	10.12	4.82
STS Launch Cost	26.63	4.69	8.40	13.54	0.00
Perigee Stage Cost	10.66	3.04	4.31	2.24	1.07
Launch Support Cost	1.63	0.47	0.66	0.34	0.16
Mission Operations	2.56	0.73	1.03	0.54	0.26
Launch Insurance	14.60	2.50	0.00	10.22	1.88
OMV/OTV Cost	0.00	0.00	0.00	0.00	0.00
Space Station Support Cost	0.00	0.00	0.00	0.00	0.00
Total Capital Expenditures	104.25	25.18	33.88	37.00	8.19

General Assumptions

Project Starting Year (1985 is base year)	-2
Month Placed in Service	36
Useful Life (in months)	120

The satellite, perigee, launch support, and mission operations costs include a 12% allocation for manufacturer G&A and a 12% fee.

Launch insurance is estimated to cost 14% of total capital cost of the satellite, STS launch, perigee stage, launch support, mission operations and launch insurance.

Table A-2.6: Capital Expenditure and General Assumptions (1985 Ku-band Satellite System)

Run Date: 03-Jun-86

OPERATING EXPENDITURE ASSUMPTIONS

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	Base Amount	Infla %	
Annual TT&C	1.275	1.00%	TT&C cost includes both fixed and variable components; only the variable component is subject to inflation. This results in an effective inflation rate of approximately 1% of the gross amount.
Annual Life Insurance (% of NPV of Revenues)	4.00%	N/A	
Annual Operations & Maintenance	0.500	4.00%	
Annual Sales & Marketing:			
Pre-operational (per Transponder)	0.075	4.00%	
Post-operational (per Transponder)	0.025	4.00%	
Annual General & Administrative:			
Pre-operational	1.000	4.00%	
Post-operational	1.500	4.00%	
Discount Factor for Life Insurance (Assumed Cost of Equity)	18.00%		

Table A-2.7: Operating Expenditure Assumptions (1985 Ku-band Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

Run Date: 17-Jun-86

FINANCING ASSUMPTIONS

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% of Capital Expenditures Funded With Debt	45.00%		
Construction Loan Terms:	Year 1	Year 2	Year 3
Interest Rate	12.81%	13.97%	12.04%
Permanent Loan Terms:			
Loan Principal (In Millions)	46.92		
Term of Loan (Months)	60		
Month of First Payment	1		
Year of First Payment	4		
Annual Interest Rate	11.00%		
Monthly Payment (Automatic)	1.02		

Interest expense is projected, including all transaction costs, to average prime plus 2 percentage points. The prime rate average for 1983 was 10.81% and was 11.97% for 1984. For the first nine months of 1985, the prime rate average was 10.04%. The 1986 first quarter prime rate avg. is 9.00% .

Year	Months Remaining	Year End Balance	Principal	Interest
1	0	0.00	0.00	0.00
2	0	0.00	0.00	0.00
3	0	0.00	0.00	0.00
4	48	39.47	7.45	4.79
5	36	31.16	8.31	3.93
6	24	21.89	9.27	2.97
7	12	11.54	10.35	1.89
8	0	0.00	11.54	0.70
9	0	0.00	0.00	0.00
10	0	0.00	0.00	0.00
11	0	0.00	0.00	0.00
12	0	0.00	0.00	0.00
13	0	0.00	0.00	0.00
14	0	0.00	0.00	0.00
15	0	0.00	0.00	0.00

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Table A-2.8: Financing Assumptions (1985 Ku-band Satellite System)

Run Date: 17-Jun-86

TAX ASSUMPTIONS

Tax Rates:

Marginal Federal Rate	46.00%	The combined Federal & State tax rates result in a 49.78% effective tax rate.
Marginal State Rate	7.00%	
Investment Tax Credit Rate	8.00%	
Depreciation Method	ACRS	
Satellite Life (For Tax Purposes)	5 Years	

Federal & State Tax Computation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Earnings Before Tax	(2.62)	(4.62)	(6.25)	16.21	10.10	12.52	14.09	14.34	36.05	33.55	34.34	32.03	33.00	0.00	0.00
State Tax	(0.18)	(0.32)	(0.44)	1.13	0.71	0.88	0.99	1.00	2.52	2.35	2.40	2.24	2.31	0.00	0.00
Federal Taxable Income	(2.44)	(4.30)	(5.81)	15.08	9.39	11.64	13.10	13.34	33.53	31.20	31.94	29.79	30.69	0.00	0.00
Federal Tax	(1.12)	(1.98)	(2.67)	6.94	4.32	5.35	6.03	6.14	15.42	14.35	14.69	13.70	14.12	0.00	0.00
Investment Tax Credit	0.00	0.00	0.00	(8.34)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Tax Cost (Benefit)	(1.30)	(2.30)	(3.11)	(0.27)	5.03	6.23	7.02	7.14	17.94	16.70	17.09	15.94	16.43	0.00	0.00

Table A-2.9: Tax Assumptions (1985 Ku-band Satellite System)

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Run Date: 17-Jun-86

FINANCIAL ANALYSIS

Page 1

DUAL TERMINAL RATE OF RETURN		INTERNAL RATE OF RETURN		NET PRESENT VALUE	
Required Return on Equity (Projected Reinvestment Rate)	18.00%	Internal Rate of Return	27.98%	Projected Cost of Equity (Discount Rate)	18.00%
Dual Terminal Rate of Return	21.89%			Net Present Value	16,444,088

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Net Income (Loss)	(1.49)	(2.32)	(2.98)	16.99	7.92	8.93	9.60	10.37	18.01	17.76	18.18	15.61	16.08	0.00	0.00
Plus: Tax Depreciation	0.00	0.00	0.00	12.46	18.28	17.45	17.45	17.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Less: Principal Payments	0.00	0.00	0.00	5.94	6.62	7.39	8.25	9.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Flow From Operations	(1.49)	(2.32)	(2.98)	23.51	19.58	18.99	18.80	18.62	18.01	17.76	18.18	15.61	16.08	0.00	0.00
Equity Investment:															
Fund Cash Deficit	1.49	2.32	2.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fund Fixed Asset Additions	11.28	15.05	15.55	3.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Equity Cash Flow	(12.77)	(17.37)	(18.53)	19.70	19.58	18.99	18.80	18.62	18.01	17.76	18.18	15.61	16.08	0.00	0.00
Dual Terminal Cash Flows	(40.80)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	438.73	0.00	0.00

Table A-3.1: Financial Analysis (1985 Hybrid Satellite System)

Run Date: 17-Jun-86

INCOME STATEMENT (CASH BASIS)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Project Revenues	0.00	0.00	0.00	49.30	49.30	49.30	49.30	49.30	45.78	44.52	44.52	38.32	38.32	0.00	0.00
Operating Expenses:															
TT&C	0.00	0.00	0.00	1.29	1.30	1.31	1.33	1.34	1.35	1.37	1.38	1.39	1.41	0.00	0.00
Life Insurance	0.00	0.00	0.00	8.52	8.08	7.56	6.95	6.23	5.38	4.51	3.54	2.40	1.30	0.00	0.00
Operations & Maintenance	0.00	0.00	0.00	0.52	0.54	0.56	0.58	0.61	0.63	0.66	0.68	0.71	0.74	0.00	0.00
Operating Income	0.00	0.00	0.00	38.97	39.38	39.87	40.44	41.12	38.42	37.98	38.92	33.82	34.87	0.00	0.00
Selling, General & Administrative:															
Sales & Marketing:															
Pre-operational	1.46	1.51	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	0.55	0.57	0.59	0.61	0.64	0.66	0.66	0.68	0.60	0.63	0.00	0.00
General & Administrative:															
Pre-operational	0.92	0.96	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	1.56	1.62	1.69	1.75	1.82	1.90	1.97	2.05	2.13	2.22	0.00	0.00
Depreciation	0.00	0.00	0.00	12.46	18.28	17.45	17.45	17.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Income Before Interest & Taxes	(2.38)	(2.47)	(2.58)	24.40	18.91	20.14	20.63	21.21	35.86	35.35	36.19	31.09	32.02	0.00	0.00
Interest Expense	0.59	2.15	3.36	3.82	3.14	2.37	1.51	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earnings Before Tax	(2.97)	(4.62)	(5.94)	20.58	15.77	17.77	19.12	20.65	35.86	35.35	36.19	31.09	32.02	0.00	0.00
Federal & State Tax	(1.48)	(2.30)	(2.96)	3.59	7.85	8.84	9.52	10.28	17.85	17.59	18.01	15.48	15.94	0.00	0.00
Net Income (Loss)	(1.49)	(2.32)	(2.98)	16.99	7.92	8.93	9.60	10.37	18.01	17.76	18.18	15.61	16.08	0.00	0.00

Table A-3.2: Income Statement (1985 Hybrid Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

Run Date: 17-Jun-86

BALANCE SHEET (CASH BASIS)

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Assets															
Cash	0.00	0.00	0.00	23.51	43.09	62.08	80.88	99.50	117.51	135.27	153.45	169.06	185.14	185.14	185.14
Fixed Assets	20.51	47.88	76.16	83.09	83.09	83.09	83.09	83.09	83.09	83.09	83.09	83.09	83.09	83.09	83.09
Accumulated Dep.	0.00	0.00	0.00	12.46	30.74	48.19	65.64	83.09	83.09	83.09	83.09	83.09	83.09	83.09	83.09
Total Assets	20.51	47.88	76.16	94.14	95.44	96.98	98.33	99.50	117.51	135.27	153.45	169.06	185.14	185.14	185.14
Liabilities & Equity															
Construction Loan	9.23	21.55	34.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Permanent Loan	0.00	0.00	0.00	31.46	24.84	17.45	9.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Liabilities	9.23	21.55	34.28	31.46	24.84	17.45	9.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity	12.77	30.14	48.67	52.48	52.48	52.48	52.48	52.48	52.48	52.48	52.48	52.48	52.48	52.48	52.48
Retained Earnings	(1.49)	(3.81)	(6.79)	10.20	18.12	27.05	36.65	47.02	65.03	82.79	100.97	116.58	132.66	132.66	132.66
Total equity	11.28	26.33	41.88	62.68	70.60	79.53	89.13	99.50	117.51	135.27	153.45	169.06	185.14	185.14	185.14
Total Liab. & Equity	20.51	47.88	76.16	94.14	95.44	96.98	98.33	99.50	117.51	135.27	153.45	169.06	185.14	185.14	185.14

Table A-3.3: Balance Sheet (1985 Hybrid Satellite System)

Run Date: 17-Jun-86

SOURCES & USES OF FUNDS STATEMENT

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash Balance Beg. Year	0.00	0.00	0.00	0.00	23.51	43.09	62.08	80.88	99.50	117.51	135.27	153.45	169.06	185.14	185.14
Sources of Funds:															
Net Income (Less Depreciation)	0.00	0.00	0.00	29.45	26.20	26.38	27.05	27.82	18.01	17.76	18.18	15.61	16.08	0.00	0.00
Increase in Construction Debt	9.23	12.32	12.73	3.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Increase in Permanent Debt	0.00	0.00	0.00	37.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity Investment	12.77	17.37	18.53	3.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Sources of Funds	22.00	29.69	31.26	73.78	26.20	26.38	27.05	27.82	18.01	17.76	18.18	15.61	16.08	0.00	0.00
Uses of Funds:															
Net Loss (Less Depreciation)	1.49	2.32	2.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fixed Assets Additions	20.51	27.37	28.28	6.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Construction Debt	0.00	0.00	0.00	37.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Permanent Debt	0.00	0.00	0.00	5.94	6.62	7.39	8.25	9.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Uses of Funds	22.00	29.69	31.26	50.27	6.62	7.39	8.25	9.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Balance End Year	0.00	0.00	0.00	23.51	43.09	62.08	80.88	99.50	117.51	135.27	153.45	169.06	185.14	185.14	185.14

Table A-3.4: Sources and Uses of Funds Statement (1985 Hybrid Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

Run Date: 03-Jun-86 | REVENUE ASSUMPTIONS -- C-BAND | Page 5

Number of Transponders:		Utilization Factor	90.00%
Protected	9		
Unprotected	2		
Preemptable	1	Frequency (C-Band)	1
Mkt. Price/Basic Transponder:			
Protected	$1.90	Bandwidth	36 MHz
Unprotected	$1.40		
Preemptable	$0.90		
		Transponder Power	8.5 Watts
Inflation Factors:			
Protected	0.00%		
Unprotected	0.00%	Degradation Curve (1=C-band, 2=Ku-Band, 3=Hybrid, 4=Other)	3
Preemptable	0.00%		

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Unprotected	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Preemptable	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.00
Operating Transponders:															
Protected	9	9	9	9	9	9	9	9	9	9	9	9	9	0	0
Unprotected	2	2	2	2	2	2	2	2	2	1	1	0	0	0	0
Preemptable	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90
Unprotected	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40
Preemptable	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Marketing Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Band Width Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Power Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total Revenues	$0.00	$0.00	$0.00	$18.72	$18.72	$18.72	$18.72	$18.72	$17.91	$16.65	$16.65	$15.39	$15.39	$0.00	$0.00

Table A-3.5a: Revenue Assumptions – C-band Transponders (1985 Hybrid Satellite System)

Run Date: 03-Jun-86

REVENUE ASSUMPTIONS -- Ku-BAND

Number of Transponders:		Utilization Factor	90.00%
Protected	5		
Unprotected	0		
Preemptable	1	Frequency (Ku-Band)	2
Mkt. Price/Basic Transponder:			
Protected	$1.90	Bandwidth	72 MHz
Unprotected	$1.40		
Preemptable	$0.90		
		Transponder Power	16.0 Watts
Inflation Factors:			
Protected	0.00%		
Unprotected	0.00%	Degradation Curve	3
Preemptable	0.00%	(1=C-Band, 2=Ku-band, 3=Hybrid, 4=Other)	

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.00
Operating Transponders:															
Protected	5	5	5	5	5	5	5	5	5	5	5	4	4	0	0
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90
Unprotected	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40
Preemptable	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Marketing Factor	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Band Width Factor	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
Power Factor	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Total Revenues	$0.00	$0.00	$0.00	$14.86	$14.86	$14.86	$14.86	$14.86	$13.58	$13.58	$13.58	$10.86	$10.86	$0.00	$0.00

Table A-3.5b: Revenue Assumptions – Ku-band Transponders (1985 Hybrid Satellite System)

Run Date: 03-Jun-86

REVENUE ASSUMPTIONS -- OTHER

Number of Transponders:		Utilization Factor	90.00%
Protected	4		
Unprotected	1		
Preemptable	1	Frequency (Other)	3
Mkt. Price/Basic Transponder:			
Protected	$1.90	Bandwidth	72 MHz
Unprotected	$1.40		
Preemptable	$0.90	Transponder Power	15.0 Watts
Inflation Factors:			
Protected	0.00%	Degradation Curve (1=C-Band, 2=Ku-band, 3=Hybrid, 4=Other)	3
Unprotected	0.00%		
Preemptable	0.00%		

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Unprotected	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Preemptable	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.00
Operating Transponders:															
Protected	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0
Unprotected	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Preemptable	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90
Unprotected	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40
Preemptable	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Marketing Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Band Width Factor	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
Power Factor	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Total Revenues	$0.00	$0.00	$0.00	$15.72	$15.72	$15.72	$15.72	$15.72	$14.29	$14.29	$14.29	$12.07	$12.07	$0.00	$0.00

Table A-3.5c: Revenue Assumptions – Other Transponders (1985 Hybrid Satellite System)

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Run Date: 17-Jun-86

*** CAPITAL EXPENDITURE AND GENERAL ASSUMPTIONS ***

Capital Expenditures	Total ($)	Payment Schedule Year 1	Year 2	Year 3	Year 4
Satellite Cost	43.87	28.54%	40.45%	21.01%	10.00%
STS Launch Cost	17.19	17.63%	31.53%	50.84%	0.00%
Perigee Stage Cost	6.21	28.54%	40.45%	21.01%	10.00%
Launch Support Cost	1.64	28.54%	40.45%	21.01%	10.00%
Mission Operations	2.55	28.54%	40.45%	21.01%	10.00%
Launch Insurance	11.63	17.14%	0.00%	70.00%	12.86%
OMV/OTV Cost	0.00	0.00%	0.00%	0.00%	0.00%
Space Station Support Cost	0.00	0.00%	0.00%	0.00%	0.00%

General Assumptions

Project Starting Year (1985 is base year)	-2
Month Placed in Service	36
Useful Life (in months)	120

Capital Expenditures	Total	Year 1	Year 2	Year 3	Year 4
Satellite Cost	43.88	12.52	17.75	9.22	4.39
STS Launch Cost	17.19	3.03	5.42	8.74	0.00
Perigee Stage Cost	6.20	1.77	2.51	1.30	0.62
Launch Support Cost	1.63	0.47	0.66	0.34	0.16
Mission Operations	2.56	0.73	1.03	0.54	0.26
Launch Insurance	11.63	1.99	0.00	8.14	1.50
OMV/OTV Cost	0.00	0.00	0.00	0.00	0.00
Space Station Support Cost	0.00	0.00	0.00	0.00	0.00
Total Capital Expenditures	83.09	20.51	27.37	28.28	6.93

The satellite, perigee, launch support, and mission operations costs include a 12% allocation for manufacturer G&A and a 12% fee.

Launch insurance is estimated to cost 14% of total capital cost of the satellite, STS launch, perigee stage, launch support, mission operations and launch insurance.

Table A-3.6: Capital Expenditure and General Assumptions (1985 Hybrid Satellite System)

Run Date: 03-Jun-86

OPERATING EXPENDITURE ASSUMPTIONS

Page 7

	Base Amount	Infla %
Annual TT&C	1.275	1.00%
Annual Life Insurance (% of NPV of Revenues)	4.00%	N/A
Annual Operations & Maintenance	0.500	4.00%
Annual Sales & Marketing:		
Pre-operational (per Transponder)	0.075	4.00%
Post-operational (per Transponder)	0.025	4.00%
Annual General & Administrative:		
Pre-operational	1.000	4.00%
Post-operational	1.500	4.00%
Discount Factor for Life Insurance (Assumed Cost of Equity)	18.00%	

TT&C cost includes both fixed and variable components; only the variable component is subject to inflation. This results in an effective inflation rate of approximately 1% of the gross amount.

Table A-3.7: Operating Expenditure Assumptions (1985 Hybrid Satellite System)

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Run Date: 17-Jun-86

FINANCING ASSUMPTIONS

Page 8

% of Capital Expenditures Funded With Debt	45.00%		
Construction Loan Terms:	Year 1	Year 2	Year 3
Interest Rate	12.81%	13.97%	12.04%
Permanent Loan Terms:			
Loan Principal (In Millions)	37.40		
Term of Loan (Months)	60		
Month of First Payment	1		
Year of First Payment	4		
Annual Interest Rate	11.00%		
Monthly Payment (Automatic)	0.81		

Interest expense is projected, including all transaction costs, to average prime plus 2 percentage points. The prime rate average for 1983 was 10.81% and was 11.97% for 1984. For the first nine months of 1985, the prime rate average was 10.04%. The 1986 first quarter prime rate avg. is 9.00% .

Year	Months Remaining	Year End Balance	Principal	Interest
1	0	0.00	0.00	0.00
2	0	0.00	0.00	0.00
3	0	0.00	0.00	0.00
4	48	31.46	5.94	3.82
5	36	24.84	6.62	3.14
6	24	17.45	7.39	2.37
7	12	9.20	8.25	1.51
8	0	0.00	9.20	0.56
9	0	0.00	0.00	0.00
10	0	0.00	0.00	0.00
11	0	0.00	0.00	0.00
12	0	0.00	0.00	0.00
13	0	0.00	0.00	0.00
14	0	0.00	0.00	0.00
15	0	0.00	0.00	0.00

Table A-3.8: Financing Assumptions (1985 Hybrid Satellite System)

Run Date: 17-Jun-86

TAX ASSUMPTIONS

Page 9

Tax Rates:
- Marginal Federal Rate 46.00%
- Marginal State Rate 7.00%

The combined Federal & State tax rates result in a 49.78% effective tax rate.

Investment Tax Credit Rate 8.00%

Depreciation Method ACRS

Satellite Life (For Tax Purposes) 5 Years

Federal & State Tax Computation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Earnings Before Tax	(2.97)	(4.62)	(5.94)	20.58	15.77	17.77	19.12	20.65	35.86	35.35	36.19	31.09	32.02	0.00	0.00
State Tax	(0.21)	(0.32)	(0.42)	1.44	1.10	1.24	1.34	1.45	2.51	2.47	2.53	2.18	2.24	0.00	0.00
Federal Taxable Income	(2.76)	(4.30)	(5.52)	19.14	14.67	16.53	17.78	19.20	33.35	32.88	33.66	28.91	29.78	0.00	0.00
Federal Tax	(1.27)	(1.98)	(2.54)	8.80	6.75	7.60	8.18	8.83	15.34	15.12	15.48	13.30	13.70	0.00	0.00
Investment Tax Credit	0.00	0.00	0.00	(6.65)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Tax Cost (Benefit)	(1.48)	(2.30)	(2.96)	3.59	7.85	8.84	9.52	10.28	17.85	17.59	18.01	15.48	15.94	0.00	0.00

Table A-3.9: Tax Assumptions (1985 Hybrid Satellite System)

Appendix B

FINANCIAL MODEL OUTPUT 1995 SATELLITE SYSTEMS

This appendix contains the Financial Model results for the four 1995 satellite designs described in Section IV:

1. Ku-band, spin-stabilized satellite (Table IV-7)
2. Ku-band, 3-axis satellite (Table IV-9)
3. Hybrid (C and Ku-bands), 3-axis satellite (Table IV-10)
4. Large Ku-band, 3-axis satellite (Table IV-13)

These results are discussed in Section V, and consist of nine pages of output for each satellite system.

The output pages for each satellite contain the following information which is described in Subsection II-4.5.1:

Page 1: Financial analysis
Page 2: Income statement (cash basis)
Page 3: Balance sheet (cash basis)
Page 4: Sources and uses of funds statement
Page 5: Revenue assumptions (three separate pages for C-band, Ku-band, and Other transponders)
Page 6: Capital expenditure and general assumptions
Page 7: Operating expenditure assumptions
Page 8: Financing assumptions
Page 9: Tax assumptions

The tables are numbered B-1.1, B-1.2, ... B-1.9 for the Ku-band spinner system, Table B-2.1 etc. for the Ku-band 3-axis system, Table B-3.1 etc. for the hybrid satellite system, and Table B-4.1 etc. for the large Ku-band 3-axis system.

The bottom line "result" is the dual terminal rate of return which is presented on page 1. Pages 5a, b, c show the revenues from lease of the transponders. Page 6 shows the breakdown of costs for the satellite.

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Run Date: 17-Jun-86

FINANCIAL ANALYSIS

DUAL TERMINAL RATE OF RETURN		INTERNAL RATE OF RETURN		NET PRESENT VALUE	
Required Return on Equity (Projected Reinvestment Rate)	18.00%	Internal Rate of Return	20.23%	Projected Cost of Equity (Discount Rate)	18.00%
Dual Terminal Rate of Return	18.91%	PROT:	1.27	Net Present Value	4,434,745
		UNPROT:	0.93		
		PREEM:	0.60		

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Net Income (Loss)	(1.53)	(2.34)	(3.38)	16.15	3.54	4.84	5.68	5.61	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Plus: Tax Depreciation	0.00	0.00	0.00	17.27	25.33	24.18	24.18	24.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Less: Principal Payments	0.00	0.00	0.00	8.23	9.18	10.24	11.42	12.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Flow From Operations	(1.53)	(2.34)	(3.38)	25.19	19.69	18.78	18.44	17.04	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Equity Investment:															
Fund Cash Deficit	1.53	2.34	3.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fund Fixed Asset Additions	14.84	19.02	24.41	5.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Equity Cash Flows	(16.37)	(21.36)	(27.79)	20.14	19.69	18.78	18.44	17.04	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Dual Terminal Cash Flows	(54.43)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	434.78	0.00	0.00

Table B-1.1: Financial Analysis (1995 Ku-band Spinner Satellite System)

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Run Date: 17-Jun-86

INCOME STATEMENT (CASH BASIS)

Page 2

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Project Revenues	0.00	0.00	0.00	48.69	48.69	48.69	48.69	46.63	45.60	43.43	43.43	39.09	39.09	0.00	0.00
Operating Expenses:															
TT&C	0.00	0.00	0.00	1.29	1.30	1.31	1.33	1.34	1.35	1.37	1.38	1.39	1.41	0.00	0.00
Life Insurance	0.00	0.00	0.00	8.39	7.95	7.43	6.83	6.11	5.34	4.48	3.55	2.45	1.33	0.00	0.00
Operations & Maintenance	0.00	0.00	0.00	0.52	0.54	0.56	0.58	0.61	0.63	0.66	0.68	0.71	0.74	0.00	0.00
Operating Income	0.00	0.00	0.00	38.49	38.90	39.39	39.95	38.57	38.28	36.92	37.82	34.54	35.61	0.00	0.00
Selling, General & Administrative:															
Sales & Marketing:															
Pre-operational	1.46	1.51	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	0.55	0.57	0.59	0.61	0.64	0.66	0.66	0.68	0.64	0.67	0.00	0.00
General & Administrative:															
Pre-operational	0.92	0.96	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	1.56	1.62	1.69	1.75	1.82	1.90	1.97	2.05	2.13	2.22	0.00	0.00
Depreciation	0.00	0.00	0.00	17.27	25.33	24.18	24.18	24.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Income Before Interest & Taxes	(2.38)	(2.47)	(2.58)	19.11	11.38	12.93	13.41	11.93	35.72	34.29	35.09	31.77	32.72	0.00	0.00
Interest Expense	0.67	2.19	4.15	5.29	4.34	3.28	2.10	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earnings Before Tax	(3.05)	(4.66)	(6.73)	13.82	7.04	9.65	11.31	11.16	35.72	34.29	35.09	31.77	32.72	0.00	0.00
Federal & State Tax	(1.52)	(2.32)	(3.35)	(2.33)	3.50	4.81	5.63	5.55	17.78	17.07	17.47	15.81	16.29	0.00	0.00
Net Income (Loss)	(1.53)	(2.34)	(3.38)	16.15	3.54	4.84	5.68	5.61	17.94	17.22	17.62	15.96	16.43	0.00	0.00

Table B-1.2: Income Statement (1995 Ku-band Spinner Satellite System)

Run Date: 17-Jun-86

BALANCE SHEET (CASH BASIS)

Page 3

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Assets															
Cash	0.00	0.00	0.00	25.19	44.88	63.66	82.10	99.14	117.08	134.30	151.92	167.88	184.31	184.31	184.31
Fixed Assets	26.98	61.57	105.95	115.14	115.14	115.14	115.14	115.14	115.14	115.14	115.14	115.14	115.14	115.14	115.14
Accumulated Dep.	0.00	0.00	0.00	17.27	42.60	66.78	90.96	115.14	115.14	115.14	115.14	115.14	115.14	115.14	115.14
Total Assets	26.98	61.57	105.95	123.06	117.42	112.02	106.28	99.14	117.08	134.30	151.92	167.88	184.31	184.31	184.31
Liabilities & Equity															
Construction Loan	12.14	27.71	47.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Permanent Loan	0.00	0.00	0.00	43.59	34.41	24.17	12.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Liabilities	12.14	27.71	47.68	43.59	34.41	24.17	12.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity	16.37	37.73	65.52	70.57	70.57	70.57	70.57	70.57	70.57	70.57	70.57	70.57	70.57	70.57	70.57
Retained Earnings	(1.53)	(3.87)	(7.25)	8.90	12.44	17.28	22.96	28.57	46.51	63.73	81.35	97.31	113.74	113.74	113.74
Total equity	14.84	33.86	58.27	79.47	83.01	87.85	93.53	99.14	117.08	134.30	151.92	167.88	184.31	184.31	184.31
Total Liab. & Equity	26.98	61.57	105.95	123.06	117.42	112.02	106.28	99.14	117.08	134.30	151.92	167.88	184.31	184.31	184.31

Table B-1.3: Balance Sheet (1995 Ku-band Spinner Satellite System)

Run Date: 17-Jun-86

SOURCES & USES OF FUNDS STATEMENT

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash Balance Beg. Year	0.00	0.00	0.00	0.00	25.19	44.88	63.66	82.10	99.14	117.08	134.30	151.92	167.88	184.31	184.31
Sources of Funds:															
Net Income (Less Depreciation)	0.00	0.00	0.00	33.42	28.87	29.02	29.86	29.79	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Increase in Construction Debt	12.14	15.57	19.97	4.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Increase in Permanent Debt	0.00	0.00	0.00	51.82	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity Investment	16.37	21.36	27.79	5.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Sources of Funds	28.51	36.93	47.76	94.43	28.87	29.02	29.86	29.79	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Uses of Funds:															
Net Loss (Less Depreciation)	1.53	2.34	3.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fixed Assets Additions	26.98	34.59	44.38	9.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Construction Debt	0.00	0.00	0.00	51.82	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Permanent Debt	0.00	0.00	0.00	8.23	9.18	10.24	11.42	12.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Uses of Funds	28.51	36.93	47.76	69.24	9.18	10.24	11.42	12.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Balance End Year	0.00	0.00	0.00	25.19	44.88	63.66	82.10	99.14	117.08	134.30	151.92	167.88	184.31	184.31	184.31

Table B-1.4: Sources and Uses of Funds Statement (1995 Ku-band Spinner Satellite System)

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Run Date: 05-Jun-86

REVENUE ASSUMPTIONS -- Ku-BAND

Number of Transponders:		Utilization Factor	90.00%
Protected	21		
Unprotected	0		
Preemptable	3	Frequency (Ku-Band)	2
Mkt. Price/Basic Transponder:			
Protected	$1.27	Bandwidth	54 MHz
Unprotected	$0.93		
Preemptable	$0.60		
Inflation Factors:		Transponder Power	50.0 Watts
Protected	0.00%		
Unprotected	0.00%	Degradation Curve (1=C-Band, 2=Ku-band, 3=Hybrid, 4=Other)	2
Preemptable	0.00%		

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.90	0.87	0.85	0.78	0.75	0.70	0.00
Operating Transponders:															
Protected	21	21	21	21	21	21	21	21	21	20	20	18	18	0	0
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	3	3	3	3	3	3	3	1	0	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27
Unprotected	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93
Preemptable	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Marketing Factor	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Band Width Factor	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Power Factor	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
Total Revenues	$0.00	$0.00	$0.00	$48.69	$48.69	$48.69	$48.69	$46.63	$45.60	$43.43	$43.43	$39.09	$39.09	$0.00	$0.00

Table B-1.5b: Revenue Assumptions – Ku-band Transponders (1995 Ku-band Spinner Satellite System)

Run Date: 17-Jun-86

*** CAPITAL EXPENDITURE AND GENERAL ASSUMPTIONS ***

Capital Expenditures	Total ($)	Payment Schedule Year 1	Year 2	Year 3	Year 4
Satellite Cost	54.32	28.54%	40.45%	21.01%	10.00%
STS Launch Cost	29.86	17.63%	31.53%	50.84%	0.00%
Perigee Stage Cost	3.76	28.54%	40.45%	21.01%	10.00%
Launch Support Cost	1.64	28.54%	40.45%	21.01%	10.00%
Mission Operations	2.55	28.54%	40.45%	21.01%	10.00%
Launch Insurance	23.03	17.14%	0.00%	70.00%	12.86%
OMV/OTV Cost	0.00	0.00%	0.00%	0.00%	0.00%
Space Station Support Cost	0.00	0.00%	0.00%	0.00%	0.00%

Capital Expenditures	Total	Year 1	Year 2	Year 3	Year 4
Satellite Cost	54.31	15.50	21.97	11.41	5.43
STS Launch Cost	29.85	5.26	9.41	15.18	0.00
Perigee Stage Cost	3.76	1.07	1.32	0.79	0.38
Launch Support Cost	1.63	0.47	0.66	0.34	0.16
Mission Operations	2.56	0.73	1.03	0.54	0.26
Launch Insurance	23.03	3.95	0.00	16.12	2.96
OMV/OTV Cost	0.00	0.00	0.00	0.00	0.00
Space Station Support Cost	0.00	0.00	0.00	0.00	0.00
Total Capital Expenditures	115.14	26.98	34.59	44.38	9.19

General Assumptions

Project Starting Year (1985 is base year)	-2
Month Placed in Service	36
Useful Life (in months)	120

The satellite, perigee, launch support, and mission operations costs include a 12% allocation for manufacturer G&A and a 12% fee.

Launch insurance is estimated to cost 20% of total capital cost of the satellite, STS launch, perigee stage, launch support, mission operations and launch insurance.

Table B-1.6: Capital Expenditure and General Assumptions (1995 Ku-band Spinner Satellite System)

ORIGINAL PAGE IS
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Run Date: 05-Jun-86

OPERATING EXPENDITURE ASSUMPTIONS

Page 7

	Base Amount	Infla %
Annual TT&C	1.275	1.00%
Annual Life Insurance (% of NPV of Revenues)	4.00%	N/A
Annual Operations & Maintenance	0.500	4.00%
Annual Sales & Marketing:		
Pre-operational (per Transponder)	0.075	4.00%
Post-operational (per Transponder)	0.025	4.00%
Annual General & Administrative:		
Pre-operational	1.000	4.00%
Post-operational	1.500	4.00%
Discount Factor for Life Insurance (Assumed Cost of Equity)	18.00%	

TT&C cost includes both fixed and variable components; only the variable component is subject to inflation. This results in an effective inflation rate of approximately 1% of the gross amount.

Table B-1.7: Operating Expenditure Assumptions (1995 Ku-band Spinner Satellite System)

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Run Date: 17-Jun-86 | FINANCING ASSUMPTIONS | Page 8

% of Capital Expenditures Funded With Debt	45.00%		
Construction Loan Terms:	Year 1	Year 2	Year 3
Interest Rate	11.00%	11.00%	11.00%
Permanent Loan Terms:			
Loan Principal (In Millions)	51.82		
Term of Loan (Months)	60		
Month of First Payment	1		
Year of First Payment	4		
Annual Interest Rate	11.00%		
Monthly Payment (Automatic)	1.13		

Interest expense is projected, including all transaction costs, to average prime plus 2 percentage points. The prime rate average for 1983 was 10.81% and was 11.97% for 1984. For the first nine months of 1985, the prime rate average was 10.04%. The 1986 first quarter prime rate avg. is 9.00% .

Year	Months Remaining	Year End Balance	Principal	Interest
1	0	0.00	0.00	0.00
2	0	0.00	0.00	0.00
3	0	0.00	0.00	0.00
4	48	43.59	8.23	5.29
5	36	34.41	9.18	4.34
6	24	24.17	10.24	3.28
7	12	12.75	11.42	2.10
8	0	0.00	12.75	0.77
9	0	0.00	0.00	0.00
10	0	0.00	0.00	0.00
11	0	0.00	0.00	0.00
12	0	0.00	0.00	0.00
13	0	0.00	0.00	0.00
14	0	0.00	0.00	0.00
15	0	0.00	0.00	0.00

Table B-1.8: Financing Assumptions (1995 Ku-band Spinner Satellite System)

Run Date: 17-Jun-86

TAX ASSUMPTIONS

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Tax Rates:		
Marginal Federal Rate	46.00%	The combined Federal & State tax rates result in a 49.78% effective tax rate.
Marginal State Rate	7.00%	
Investment Tax Credit Rate	8.00%	
Depreciation Method	ACRS	
Satellite Life (For Tax Purposes)	5 Years	

Federal & State Tax Computation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Earnings Before Tax	(3.05)	(4.66)	(6.73)	13.82	7.04	9.65	11.31	11.16	35.72	34.29	35.09	31.77	32.72	0.00	0.00
State Tax	(0.21)	(0.33)	(0.47)	0.97	0.49	0.68	0.79	0.78	2.50	2.40	2.46	2.22	2.29	0.00	0.00
Federal Taxable Income	(2.84)	(4.33)	(6.26)	12.85	6.55	8.97	10.52	10.38	33.22	31.89	32.63	29.55	30.43	0.00	0.00
Federal Tax	(1.31)	(1.99)	(2.88)	5.91	3.01	4.13	4.84	4.77	15.28	14.67	15.01	13.59	14.00	0.00	0.00
Investment Tax Credit	0.00	0.00	0.00	(9.21)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Tax Cost (Benefit)	(1.52)	(2.32)	(3.35)	(2.33)	3.50	4.81	5.63	5.55	17.78	17.07	17.47	15.81	16.29	0.00	0.00

Table B-1.9: Tax Assumptions (1995 Ku-band Spinner Satellite System)

Run Date: 16-Jun-86

FINANCIAL ANALYSIS

Page 1

DUAL TERMINAL RATE OF RETURN		INTERNAL RATE OF RETURN		NET PRESENT VALUE	
Required Return on Equity (Projected Reinvestment Rate)	18.00%	Internal Rate of Return	19.89%	Projected Cost of Equity (Discount Rate)	18.00%
		PROT:	1.27		
Dual Terminal Rate of Return	18.77%	UNPROT:	0.93	Net Present Value	3,793,525
		PREEM:	0.60		

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Net Income (Loss)	(1.54)	(2.36)	(3.41)	16.12	3.33	4.65	5.49	5.43	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Plus: Tax Depreciation	0.00	0.00	0.00	17.52	25.69	24.52	24.52	24.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Less: Principal Payments	0.00	0.00	0.00	8.34	9.31	10.39	11.58	12.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Flow From Operations	(1.54)	(2.36)	(3.41)	25.30	19.71	18.78	18.43	17.02	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Equity Investment:															
Fund Cash Deficit	1.54	2.36	3.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fund Fixed Asset Additions	15.20	19.42	24.33	5.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Equity Cash Flows	(16.74)	(21.78)	(27.74)	20.03	19.71	18.78	18.43	17.02	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Dual Terminal Cash Flows	(55.12)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	434.30	0.00	0.00

Table B-2.1: Financial Analysis (1995 Ku-band 3-axis Satellite System)

ORIGINAL PAGE IS
OF POOR QUALITY

Run Date: 16-Jun-86

INCOME STATEMENT (CASH BASIS)

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Project Revenues	0.00	0.00	0.00	48.69	48.69	48.69	48.69	46.63	45.60	43.43	43.43	39.09	39.09	0.00	0.00
Operating Expenses:															
TT&C	0.00	0.00	0.00	1.29	1.30	1.31	1.33	1.34	1.35	1.37	1.38	1.39	1.41	0.00	0.00
Life Insurance	0.00	0.00	0.00	8.39	7.95	7.43	6.83	6.11	5.34	4.48	3.55	2.45	1.33	0.00	0.00
Operations & Maintenance	0.00	0.00	0.00	0.52	0.54	0.56	0.58	0.61	0.63	0.66	0.68	0.71	0.74	0.00	0.00
Operating Income	0.00	0.00	0.00	38.49	38.90	39.39	39.95	38.57	38.28	36.92	37.82	34.54	35.61	0.00	0.00
Selling, General & Administrative:															
Sales & Marketing:															
Pre-operational	1.46	1.51	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	0.55	0.57	0.59	0.61	0.64	0.66	0.66	0.68	0.64	0.67	0.00	0.00
General & Administrative:															
Pre-operational	0.92	0.96	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	1.56	1.62	1.69	1.75	1.82	1.90	1.97	2.05	2.13	2.22	0.00	0.00
Depreciation	0.00	0.00	0.00	17.52	25.69	24.52	24.52	24.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Income Before Interest & Taxes	(2.38)	(2.47)	(2.58)	18.86	11.02	12.59	13.07	11.59	35.72	34.29	35.09	31.77	32.72	0.00	0.00
Interest Expense	0.68	2.24	4.21	5.37	4.40	3.32	2.13	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earnings Before Tax	(3.06)	(4.71)	(6.79)	13.49	6.62	9.27	10.94	10.81	35.72	34.29	35.09	31.77	32.72	0.00	0.00
Federal & State Tax	(1.52)	(2.35)	(3.38)	(2.63)	3.29	4.62	5.45	5.38	17.78	17.07	17.47	15.81	16.29	0.00	0.00
Net Income (Loss)	(1.54)	(2.36)	(3.41)	16.12	3.33	4.65	5.49	5.43	17.94	17.22	17.62	15.96	16.43	0.00	0.00

Table B-2.2: Income Statement (1995 Ku-band 3-axis Satellite System)

Run Date: 16-Jun-86

BALANCE SHEET (CASH BASIS)

Page 3

Assets	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash	0.00	0.00	0.00	25.30	45.01	63.79	82.22	99.24	117.18	134.40	152.02	167.98	184.41	184.41	184.41
Fixed Assets	27.64	62.95	107.19	116.77	116.77	116.77	116.77	116.77	116.77	116.77	116.77	116.77	116.77	116.77	116.77
Accumulated Dep.	0.00	0.00	0.00	17.52	43.21	67.73	92.25	116.77	116.77	116.77	116.77	116.77	116.77	116.77	116.77
Total Assets	27.64	62.95	107.19	124.55	118.57	112.83	106.74	99.24	117.18	134.40	152.02	167.98	184.41	184.41	184.41
Liabilities & Equity															
Construction Loan	12.44	28.33	48.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Permanent Loan	0.00	0.00	0.00	44.21	34.90	24.51	12.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Liabilities	12.44	28.33	48.24	44.21	34.90	24.51	12.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity	16.74	38.53	66.27	71.54	71.54	71.54	71.54	71.54	71.54	71.54	71.54	71.54	71.54	71.54	71.54
Retained Earnings	(1.54)	(3.91)	(7.32)	8.80	12.13	16.78	22.27	27.70	45.64	62.86	80.48	96.44	112.87	112.87	112.87
Total equity	15.20	34.62	58.95	80.34	83.67	88.32	93.81	99.24	117.18	134.40	152.02	167.98	184.41	184.41	184.41
Total Liab. & Equity	27.64	62.95	107.19	124.55	118.57	112.83	106.74	99.24	117.18	134.40	152.02	167.98	184.41	184.41	184.41

Table B-2.3: Balance Sheet (1995 Ku-band 3-axis Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

Run Date: 16-Jun-86

SOURCES & USES OF FUNDS STATEMENT

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash Balance Beg. Year	0.00	0.00	0.00	0.00	25.30	45.01	63.79	82.22	99.24	117.18	134.40	152.02	167.98	184.41	184.41
Sources of Funds:															
Net Income (Less Depreciation)	0.00	0.00	0.00	33.64	29.02	29.17	30.01	29.95	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Increase in Construction Debt	12.44	15.89	19.91	4.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Increase in Permanent Debt	0.00	0.00	0.00	52.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity Investment	16.74	21.78	27.74	5.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Sources of Funds	29.18	37.67	47.65	95.77	29.02	29.17	30.01	29.95	17.94	17.22	17.62	15.96	16.43	0.00	0.00
Uses of Funds:															
Net Loss (Less Depreciation)	1.54	2.36	3.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fixed Assets Additions	27.64	35.31	44.24	9.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Construction Debt	0.00	0.00	0.00	52.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Permanent Debt	0.00	0.00	0.00	8.34	9.31	10.39	11.58	12.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Uses of Funds	29.18	37.67	47.65	70.47	9.31	10.39	11.58	12.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Balance End Year	0.00	0.00	0.00	25.30	45.01	63.79	82.22	99.24	117.18	134.40	152.02	167.98	184.41	184.41	184.41

Table B-2.4: Sources and Uses of Funds Statement (1995 Ku-band 3-axis Satellite System)

Run Date: 05-Jun-86

REVENUE ASSUMPTIONS -- Ku-BAND

Number of Transponders:		Utilization Factor	90.00%
Protected	21		
Unprotected	0		
Preemptable	3	Frequency (Ku-Band)	2
Mkt. Price/Basic Transponder:			
Protected	$1.27	Bandwidth	54 MHz
Unprotected	$0.93		
Preemptable	$0.60		
Inflation Factors:		Transponder Power	50.0 Watts
Protected	0.00%		
Unprotected	0.00%	Degradation Curve (1=C-Band, 2=Ku-band, 3=Hybrid, 4=Other)	2
Preemptable	0.00%		

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.90	0.87	0.85	0.78	0.75	0.70	0.00
Operating Transponders:															
Protected	21	21	21	21	21	21	21	21	21	20	20	18	18	0	0
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	3	3	3	3	3	3	3	1	0	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27
Unprotected	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93
Preemptable	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Marketing Factor	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Band Width Factor	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Power Factor	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
Total Revenues	$0.00	$0.00	$0.00	$48.69	$48.69	$48.69	$48.69	$46.63	$45.60	$43.43	$43.43	$39.09	$39.09	$0.00	$0.00

Table B-2.5b: Revenue Assumptions – Ku-band Transponders (1995 Ku-band 3-axis Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

Run Date: 16-Jun-86

*** CAPITAL EXPENDITURE AND GENERAL ASSUMPTIONS ***

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Capital Expenditures	Total ($)	Payment Schedule Year 1	Year 2	Year 3	Year 4
Satellite Cost	50.85	28.54%	40.45%	21.01%	10.00%
STS Launch Cost	27.71	17.63%	31.53%	50.84%	0.00%
Perigee Stage Cost	10.66	28.54%	40.45%	21.01%	10.00%
Launch Support Cost	1.64	28.54%	40.45%	21.01%	10.00%
Mission Operations	2.55	28.54%	40.45%	21.01%	10.00%
Launch Insurance	23.35	17.14%	0.00%	70.00%	12.86%
OMV/OTV Cost	0.00	0.00%	0.00%	0.00%	0.00%
Space Station Support Cost	0.00	0.00%	0.00%	0.00%	0.00%

Capital Expenditures	Total	Year 1	Year 2	Year 3	Year 4
Satellite Cost	50.85	14.51	20.57	10.68	5.09
STS Launch Cost	27.72	4.89	8.74	14.09	0.00
Perigee Stage Cost	10.66	3.04	4.31	2.24	1.07
Launch Support Cost	1.63	0.47	0.66	0.34	0.16
Mission Operations	2.56	0.73	1.03	0.54	0.26
Launch Insurance	23.35	4.00	0.00	16.35	3.00
OMV/OTV Cost	0.00	0.00	0.00	0.00	0.00
Space Station Support Cost	0.00	0.00	0.00	0.00	0.00
Total Capital Expenditures	116.77	27.64	35.31	44.24	9.58

General Assumptions

General Assumptions	
Project Starting Year (1985 is base year)	-2
Month Placed in Service	36
Useful Life (in months)	120

The satellite, perigee, launch support, and mission operations costs include a 12% allocation for manufacturer G&A and a 12% fee.

Launch insurance is estimated to cost 20% of total capital cost of the satellite, STS launch, perigee stage, launch support, mission operations and launch insurance.

Table B-2.6: Capital Expenditure and General Assumptions (1995 Ku-band 3-axis Satellite System)

Run Date: 05-Jun-86

OPERATING EXPENDITURE ASSUMPTIONS

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	Base Amount	Infla %	
Annual TT&C	1.275	1.00%	TT&C cost includes both fixed and variable components; only the variable component is subject to inflation. This results in an effective inflation rate of approximately 1% of the gross amount.
Annual Life Insurance (% of NPV of Revenues)	4.00%	N/A	
Annual Operations & Maintenance	0.500	4.00%	
Annual Sales & Marketing:			
Pre-operational (per Transponder)	0.075	4.00%	
Post-operational (per Transponder)	0.025	4.00%	
Annual General & Administrative:			
Pre-operational	1.000	4.00%	
Post-operational	1.500	4.00%	
Discount Factor for Life Insurance (Assumed Cost of Equity)	18.00%		

Table B-2.7: Operating Expenditure Assumptions (1995 Ku-band 3-axis Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

Run Date: 16-Jun-86

FINANCING ASSUMPTIONS

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% of Capital Expenditures Funded With Debt	45.00%		
Construction Loan Terms:	Year 1	Year 2	Year 3
Interest Rate	11.00%	11.00%	11.00%
Permanent Loan Terms:			
Loan Principal (In Millions)	52.55		
Term of Loan (Months)	60		
Month of First Payment	1		
Year of First Payment	4		
Annual Interest Rate	11.00%		
Monthly Payment (Automatic)	1.14		

Interest expense is projected, including all transaction costs, to average prime plus 2 percentage points. The prime rate average for 1983 was 10.81% and was 11.97% for 1984. For the first nine months of 1985, the prime rate average was 10.04%. The 1986 first quarter prime rate avg. is 9.00% .

Year	Months Remaining	Year End Balance	Principal	Interest
1	0	0.00	0.00	0.00
2	0	0.00	0.00	0.00
3	0	0.00	0.00	0.00
4	48	44.21	8.34	5.37
5	36	34.90	9.31	4.40
6	24	24.51	10.39	3.32
7	12	12.93	11.58	2.13
8	0	0.00	12.93	0.78
9	0	0.00	0.00	0.00
10	0	0.00	0.00	0.00
11	0	0.00	0.00	0.00
12	0	0.00	0.00	0.00
13	0	0.00	0.00	0.00
14	0	0.00	0.00	0.00
15	0	0.00	0.00	0.00

Table B-2.8: Financing Assumptions (1995 Ku-band 3-axis Satellite System)

Run Date: 16-Jun-86

TAX ASSUMPTIONS

Page 9

Tax Rates:

Marginal Federal Rate	46.00%	The combined Federal & State tax rates result in a 49.78% effective tax rate.
Marginal State Rate	7.00%	
Investment Tax Credit Rate	8.00%	
Depreciation Method	ACRS	
Satellite Life (For Tax Purposes)	5 Years	

Federal & State Tax Computation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Earnings Before Tax	(3.06)	(4.71)	(6.79)	13.49	6.62	9.27	10.94	10.81	35.72	34.29	35.09	31.77	32.72	0.00	0.00
State Tax	(0.21)	(0.33)	(0.48)	0.94	0.46	0.65	0.77	0.76	2.50	2.40	2.46	2.22	2.29	0.00	0.00
Federal Taxable Income	(2.85)	(4.38)	(6.31)	12.55	6.16	8.62	10.17	10.05	33.22	31.89	32.63	29.55	30.43	0.00	0.00
Federal Tax	(1.31)	(2.02)	(2.90)	5.77	2.83	3.97	4.68	4.62	15.28	14.67	15.01	13.59	14.00	0.00	0.00
Investment Tax Credit	0.00	0.00	0.00	(9.34)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Tax Cost (Benefit)	(1.52)	(2.35)	(3.38)	(2.63)	3.29	4.62	5.45	5.38	17.78	17.07	17.47	15.81	16.29	0.00	0.00

Table B-2.9: Tax Assumptions (1995 Ku-band 3-axis Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

Run Date: 18-Jun-86

FINANCIAL ANALYSIS

DUAL TERMINAL RATE OF RETURN		INTERNAL RATE OF RETURN		NET PRESENT VALUE	
Required Return on Equity (Projected Reinvestment Rate)	18.00%	Internal Rate of Return	28.06%	Projected Cost of Equity (Discount Rate)	18.00%
Dual Terminal Rate of Return	21.90%	PROT: 1.27 UNPROT: 0.93 PREEM: 0.60		Net Present Value	27,263,844

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Net Income (Loss)	(2.51)	(3.52)	(4.78)	27.72	12.59	14.25	15.37	16.65	30.32	29.97	29.71	27.71	27.18	0.00	0.00
Plus: Tax Depreciation	0.00	0.00	0.00	20.83	30.54	29.16	29.16	29.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Less: Principal Payments	0.00	0.00	0.00	9.92	11.06	12.35	13.77	15.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Flow From Operations	(2.51)	(3.52)	(4.78)	38.63	32.07	31.06	30.76	30.44	30.32	29.97	29.71	27.71	27.18	0.00	0.00
Equity Investment:															
Fund Cash Deficit	2.51	3.52	4.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fund Fixed Asset Additions	17.93	22.97	29.34	6.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Equity Cash Flows	(20.44)	(26.49)	(34.12)	32.50	32.07	31.06	30.76	30.44	30.32	29.97	29.71	27.71	27.18	0.00	0.00
Dual Terminal Cash Flows	(67.39)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	725.59	0.00	0.00

Table B-3.1: Financial Analysis (1995 Hybrid Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

Run Date: 18-Jun-86

INCOME STATEMENT (CASH BASIS)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Project Revenues	0.00	0.00	0.00	78.53	78.53	78.53	78.53	78.53	74.50	72.54	70.57	64.87	62.07	0.00	0.00
Operating Expenses:															
TT&C	0.00	0.00	0.00	1.29	1.30	1.31	1.33	1.34	1.35	1.37	1.38	1.39	1.41	0.00	0.00
Life Insurance	0.00	0.00	0.00	13.65	12.96	12.16	11.20	10.08	8.75	7.35	5.77	3.98	2.10	0.00	0.00
Operations & Maintenance	0.00	0.00	0.00	0.52	0.54	0.56	0.58	0.61	0.63	0.66	0.68	0.71	0.74	0.00	0.00
Operating Income	0.00	0.00	0.00	63.07	63.73	64.50	65.42	66.50	63.77	63.16	62.74	58.79	57.82	0.00	0.00
Selling, General & Administrative:															
Sales & Marketing:															
Pre-operational	3.26	3.39	3.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	1.22	1.27	1.32	1.37	1.43	1.49	1.51	1.54	1.49	1.48	0.00	0.00
General & Administrative:															
Pre-operational	0.92	0.96	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	1.56	1.62	1.69	1.75	1.82	1.90	1.97	2.05	2.13	2.22	0.00	0.00
Depreciation	0.00	0.00	0.00	20.83	30.54	29.16	29.16	29.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Income Before Interest & Taxes	(4.18)	(4.35)	(4.53)	39.46	30.30	32.33	33.14	34.09	60.38	59.68	59.15	55.17	54.12	0.00	0.00
Interest Expense	0.81	2.65	5.00	6.38	5.24	3.95	2.53	0.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earnings Before Tax	(4.99)	(7.00)	(9.53)	33.08	25.06	28.38	30.61	33.16	60.38	59.68	59.15	55.17	54.12	0.00	0.00
Federal & State Tax	(2.48)	(3.48)	(4.75)	5.36	12.47	14.13	15.24	16.51	30.06	29.71	29.44	27.46	26.94	0.00	0.00
Net Income (Loss)	(2.51)	(3.52)	(4.78)	27.72	12.59	14.25	15.37	16.65	30.32	29.97	29.71	27.71	27.18	0.00	0.00

Table B-3.2: Income Statement (1995 Hybrid Satellite System)

Run Date: 18-Jun-86

BALANCE SHEET (CASH BASIS)

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Assets															
Cash	0.00	0.00	0.00	38.63	70.70	101.76	132.52	162.96	193.28	223.25	252.96	280.67	307.85	307.85	307.85
Fixed Assets	32.60	74.36	127.70	138.84	138.84	138.84	138.84	138.84	138.84	138.84	138.84	138.84	138.84	138.84	138.84
Accumulated Dep.	0.00	0.00	0.00	20.83	51.37	80.53	109.69	138.85	138.85	138.85	138.85	138.85	138.85	138.85	138.85
Total Assets	32.60	74.36	127.70	156.64	158.17	160.07	161.67	162.95	193.27	223.24	252.95	280.66	307.84	307.84	307.84
Liabilities & Equity															
Construction Loan	14.67	33.46	57.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Permanent Loan	0.00	0.00	0.00	52.55	41.49	29.14	15.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Liabilities	14.67	33.46	57.46	52.55	41.49	29.14	15.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity	20.44	46.92	81.04	87.17	87.17	87.17	87.17	87.17	87.17	87.17	87.17	87.17	87.17	87.17	87.17
Retained Earnings	(2.51)	(6.02)	(10.80)	16.92	29.51	43.76	59.13	75.78	106.10	136.07	165.78	193.49	220.67	220.67	220.67
Total equity	17.93	40.90	70.24	104.09	116.68	130.93	146.30	162.95	193.27	223.24	252.95	280.66	307.84	307.84	307.84
Total Liab. & Equity	32.60	74.36	127.70	156.64	158.17	160.07	161.67	162.95	193.27	223.24	252.95	280.66	307.84	307.84	307.84

Table B-3.3: Balance Sheet (1995 Hybrid Satellite System)

ORIGINAL PAGE IS
OF POOR QUALITY

Run Date: 18-Jun-86

SOURCES & USES OF FUNDS STATEMENT

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash Balance Beg. Year	0.00	0.00	0.00	0.00	38.63	70.70	101.76	132.52	162.96	193.28	223.25	252.96	280.67	307.85	307.85
Sources of Funds:															
Net Income (Less Depreciation)	0.00	0.00	0.00	48.55	43.13	43.41	44.53	45.81	30.32	29.97	29.71	27.71	27.18	0.00	0.00
Increase in Construction Debt	14.67	18.79	24.00	5.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Increase in Permanent Debt	0.00	0.00	0.00	62.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity Investment	20.44	26.49	34.12	6.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Sources of Funds	35.11	45.28	58.12	122.16	43.13	43.41	44.53	45.81	30.32	29.97	29.71	27.71	27.18	0.00	0.00
Uses of Funds:															
Net Loss (Less Depreciation)	2.51	3.52	4.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fixed Assets Additions	32.60	41.76	53.34	11.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Construction Debt	0.00	0.00	0.00	62.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Permanent Debt	0.00	0.00	0.00	9.92	11.06	12.35	13.77	15.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Uses of Funds	35.11	45.28	58.12	83.53	11.06	12.35	13.77	15.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Balance End Year	0.00	0.00	0.00	38.63	70.70	101.76	132.52	162.96	193.28	223.25	252.96	280.67	307.85	307.85	307.85

Table B-3.4: Sources and Uses of Funds Statement (1995 Hybrid Satellite System)

Run Date: 05-Jun-86	REVENUE ASSUMPTIONS -- C-BAND	Page 5

Number of Transponders:		Utilization Factor	90.00%
Protected	22		
Unprotected	0		
Preemptable	2	Frequency (C-Band)	1
Mkt. Price/Basic Transponder:			
Protected	$1.27	Bandwidth	36 MHz
Unprotected	$0.93		
Preemptable	$0.60		
		Transponder Power	10.0 Watts
Inflation Factors:			
Protected	0.00%		
Unprotected	0.00%	Degradation Curve	3
Preemptable	0.00%	(1=C-band, 2=Ku-Band, 3=Hybrid, 4=Other)	

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.00
Operating Transponders:															
Protected	22	22	22	22	22	22	22	22	22	21	20	19	18	0	0
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27
Unprotected	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93
Preemptable	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Marketing Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Band Width Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Power Factor	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Total Revenues	$0.00	$0.00	$0.00	$27.56	$27.56	$27.56	$27.56	$27.56	$26.43	$25.23	$24.02	$22.82	$21.62	$0.00	$0.00

Table B-3.5a: Revenue Assumptions – C-band Transponders (1995 Hybrid Satellite System)

Run Date: 05-Jun-86

REVENUE ASSUMPTIONS -- Ku-BAND

Number of Transponders:	
Protected	20
Unprotected	0
Preemptable	4
Mkt. Price/Basic Transponder:	
Protected	$1.27
Unprotected	$0.93
Preemptable	$0.60
Inflation Factors:	
Protected	0.00%
Unprotected	0.00%
Preemptable	0.00%

Utilization Factor	90.00%
Frequency (Ku-Band)	2
Bandwidth	36 MHz
Transponder Power	33.0 Watts
Degradation Curve (1=C-Band, 2=Ku-band, 3=Hybrid, 4=Other)	3

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.00
Operating Transponders:															
Protected	20	20	20	20	20	20	20	20	20	20	20	19	18	0	0
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	4	4	4	4	4	4	4	4	2	1	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27
Unprotected	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93
Preemptable	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Marketing Factor	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Band Width Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Power Factor	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
Total Revenues	$0.00	$0.00	$0.00	$35.10	$35.10	$35.10	$35.10	$35.10	$33.58	$32.82	$32.06	$30.46	$28.86	$0.00	$0.00

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Table B-3.5b: Revenue Assumptions – Ku-band Transponders (1995 Hybrid Satellite System)

Run Date: 05-Jun-86

REVENUE ASSUMPTIONS -- OTHER

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Number of Transponders:		Utilization Factor	90.00%
Protected	5		
Unprotected	0		
Preemptable	1	Frequency (Other)	3
Mkt. Price/Basic Transponder:			
Protected	$1.27	Bandwidth	72 MHz
Unprotected	$0.93		
Preemptable	$0.60		
		Transponder Power	65.0 Watts
Inflation Factors:			
Protected	0.00%		
Unprotected	0.00%	Degradation Curve (1=C-Band, 2=Ku-band, 3=Hybrid, 4=Other)	3
Preemptable	0.00%		

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.00
Operating Transponders:															
Protected	5	5	5	5	5	5	5	5	5	5	5	4	4	0	0
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27	$1.27
Unprotected	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93	$0.93
Preemptable	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60
Utilization Factor	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.00
Frequency Factor	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	1.00	1.00
Marketing Factor	1.00	1.00	1.00	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.00	1.00
Band Width Factor	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
Power Factor	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
Total Revenues	$0.00	$0.00	$0.00	$15.87	$15.87	$15.87	$15.87	$15.87	$14.49	$14.49	$14.49	$11.59	$11.59	$0.00	$0.00

Table B-3.5c: Revenue Assumptions – Other Transponders (1995 Hybrid Satellite System)

Run Date: 18-Jun-86

CAPITAL EXPENDITURE AND GENERAL ASSUMPTIONS

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Capital Expenditures	Total ($)	Payment Schedule Year 1	Year 2	Year 3	Year 4
Satellite Cost	64.58	28.54%	40.45%	21.01%	10.00%
STS Launch Cost	35.40	17.63%	31.53%	50.84%	0.00%
Perigee Stage Cost	6.90	28.54%	40.45%	21.01%	10.00%
Launch Support Cost	1.64	28.54%	40.45%	21.01%	10.00%
Mission Operations	2.55	28.54%	40.45%	21.01%	10.00%
Launch Insurance	27.77	17.14%	0.00%	70.00%	12.86%
OMV/OTV Cost	0.00	0.00%	0.00%	0.00%	0.00%
Space Station Support Cost	0.00	0.00%	0.00%	0.00%	0.00%

General Assumptions

Project Starting Year (1985 is base year)	-2
Month Placed in Service	36
Useful Life (in months)	120

Capital Expenditures	Total	Year 1	Year 2	Year 3	Year 4
Satellite Cost	64.58	18.43	26.12	13.57	6.46
STS Launch Cost	35.40	6.24	11.16	18.00	0.00
Perigee Stage Cost	6.90	1.97	2.79	1.45	0.69
Launch Support Cost	1.63	0.47	0.66	0.34	0.16
Mission Operations	2.56	0.73	1.03	0.54	0.26
Launch Insurance	27.77	4.76	0.00	19.44	3.57
OMV/OTV Cost	0.00	0.00	0.00	0.00	0.00
Space Station Support Cost	0.00	0.00	0.00	0.00	0.00
Total Capital Expenditures	138.84	32.60	41.76	53.34	11.14

The satellite, perigee, launch support, and mission operations costs include a 12% allocation for manufacturer G&A and a 12% fee.

Launch insurance is estimated to cost 20% of the total capital cost of the satellite, STS launch, perigee stage, launch support, mission operations and launch insurance.

Table B-3.6: Capital Expenditure and General Assumptions (1995 Hybrid Satellite System)

Run Date: 05-Jun-86

OPERATING EXPENDITURE ASSUMPTIONS

Page 7

	Base Amount	Infla %
Annual TT&C	1.275	1.00%
Annual Life Insurance (% of NPV of Revenues)	4.00%	N/A
Annual Operations & Maintenance	0.500	4.00%
Annual Sales & Marketing:		
Pre-operational (per Transponder)	0.075	4.00%
Post-operational (per Transponder)	0.025	4.00%
Annual General & Administrative:		
Pre-operational	1.000	4.00%
Post-operational	1.500	4.00%
Discount Factor for Life Insurance (Assumed Cost of Equity)	18.00%	

TT&C cost includes both fixed and variable components; only the variable component is subject to inflation. This results in an effective inflation rate of approximately 1% of the gross amount.

Table B-3.7: Operating Expenditure Assumptions (1995 Hybrid Satellite System)

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% of Capital Expenditures Funded With Debt	45.00%		
Construction Loan Terms:	Year 1	Year 2	Year 3
Interest Rate	11.00%	11.00%	11.00%
Permanent Loan Terms:			
Loan Principal (In Millions)	62.47		
Term of Loan (Months)	60		
Month of First Payment	1		
Year of First Payment	4		
Annual Interest Rate	11.00%		
Monthly Payment (Automatic)	1.36		

Interest expense is projected, including all transaction costs, to average prime plus 2 percentage points. The prime rate average for 1983 was 10.81% and was 11.97% for 1984. For the first nine months of 1985, the prime rate average was 10.04%. The 1986 first quarter prime rate avg. is 9.00% .

Year	Months Remaining	Year End Balance	Principal	Interest
1	0	0.00	0.00	0.00
2	0	0.00	0.00	0.00
3	0	0.00	0.00	0.00
4	48	52.55	9.92	6.38
5	36	41.49	11.06	5.24
6	24	29.14	12.35	3.95
7	12	15.37	13.77	2.53
8	0	0.00	15.37	0.93
9	0	0.00	0.00	0.00
10	0	0.00	0.00	0.00
11	0	0.00	0.00	0.00
12	0	0.00	0.00	0.00
13	0	0.00	0.00	0.00
14	0	0.00	0.00	0.00
15	0	0.00	0.00	0.00

Table B-3.8: Financing Assumptions (1995 Hybrid Satellite System)

Run Date: 18-Jun-86

TAX ASSUMPTIONS

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Tax Rates:		
Marginal Federal Rate	46.00%	The combined Federal & State tax rates result in a 49.78% effective tax rate.
Marginal State Rate	7.00%	
Investment Tax Credit Rate	8.00%	
Depreciation Method	ACRS	
Satellite Life (For Tax Purposes)	5 Years	

Federal & State Tax Computation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Earnings Before Tax	(4.99)	(7.00)	(9.53)	33.08	25.06	28.38	30.61	33.16	60.38	59.68	59.15	55.17	54.12	0.00	0.00
State Tax	(0.35)	(0.49)	(0.67)	2.32	1.75	1.99	2.14	2.32	4.23	4.18	4.14	3.86	3.79	0.00	0.00
Federal Taxable Income	(4.64)	(6.51)	(8.86)	30.76	23.31	26.39	28.47	30.84	56.15	55.50	55.01	51.31	50.33	0.00	0.00
Federal Tax	(2.13)	(2.99)	(4.08)	14.15	10.72	12.14	13.10	14.19	25.83	25.53	25.30	23.60	23.15	0.00	0.00
Investment Tax Credit	0.00	0.00	0.00	(11.11)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Tax Cost (Benefit)	(2.48)	(3.48)	(4.75)	5.36	12.47	14.13	15.24	16.51	30.06	29.71	29.44	27.46	26.94	0.00	0.00

Table B-3.9: Tax Assumptions (1995 Hybrid Satellite System)

Run Date: 16-Jun-86

FINANCIAL ANALYSIS

DUAL TERMINAL RATE OF RETURN		INTERNAL RATE OF RETURN		NET PRESENT VALUE	
Required Return on Equity (Projected Reinvestment Rate)	18.00%	Internal Rate of Return	31.34%	Projected Cost of Equity (Discount Rate)	18.00%
Dual Terminal Rate of Return	23.02%	PROT:	1.04	Net Present Value	58,755,351
		UNPROT:	0.77		
		PREEM:	0.49		

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Net Income (Loss)	(4.86)	(6.48)	(8.48)	51.16	27.82	30.57	32.49	30.27	52.16	50.70	50.63	47.57	47.13	0.00	0.00
Plus: Tax Depreciation	0.00	0.00	0.00	32.31	47.38	45.23	45.23	45.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Less: Principal Payments	0.00	0.00	0.00	15.39	17.16	19.16	21.37	23.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Flow From Operations	(4.86)	(6.48)	(8.48)	68.08	58.04	56.64	56.35	51.66	52.16	50.70	50.63	47.57	47.13	0.00	0.00
Equity Investment:															
Fund Cash Deficit	4.86	6.48	8.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fund Fixed Asset Additions	28.25	36.00	44.29	9.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Equity Cash Flows	(33.11)	(42.48)	(52.77)	58.17	58.04	56.64	56.35	51.66	52.16	50.70	50.63	47.57	47.13	0.00	0.00
Dual Terminal Cash Flows	(107.01)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,285.10	0.00	0.00

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Table B-4.1: Financial Analysis (1995 Large Ku-band Satellite System)

Run Date: 16-Jun-86

INCOME STATEMENT (CASH BASIS)

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Project Revenues	0.00	0.00	0.00	139.68	139.68	139.68	139.68	130.63	125.46	120.28	117.70	108.64	104.76	0.00	0.00
Operating Expenses:															
TT&C	0.00	0.00	0.00	1.29	1.30	1.31	1.33	1.34	1.35	1.37	1.38	1.39	1.41	0.00	0.00
Life Insurance	0.00	0.00	0.00	23.72	22.40	20.84	19.01	16.84	14.65	12.26	9.66	6.69	3.55	0.00	0.00
Operations & Maintenance	0.00	0.00	0.00	0.52	0.54	0.56	0.58	0.61	0.63	0.66	0.68	0.71	0.74	0.00	0.00
Operating Income	0.00	0.00	0.00	114.15	115.44	116.97	118.76	111.84	108.83	105.99	105.98	99.85	99.06	0.00	0.00
Selling, General & Administrative:															
Sales & Marketing:															
Pre-operational	7.49	7.79	8.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	2.81	2.92	3.04	3.16	3.07	3.07	3.06	3.11	2.99	3.00	0.00	0.00
General & Administrative:															
Pre-operational	0.92	0.96	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post-operational	0.00	0.00	0.00	1.56	1.62	1.69	1.75	1.82	1.90	1.97	2.05	2.13	2.22	0.00	0.00
Depreciation	0.00	0.00	0.00	32.31	47.38	45.23	45.23	45.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Income Before Interest & Taxes	(8.41)	(8.75)	(9.10)	77.47	63.52	67.01	68.62	61.72	103.86	100.96	100.82	94.73	93.84	0.00	0.00
Interest Expense	1.27	4.16	7.78	9.90	8.13	6.13	3.92	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earnings Before Tax	(9.68)	(12.91)	(16.88)	67.57	55.39	60.88	64.70	60.27	103.86	100.96	100.82	94.73	93.84	0.00	0.00
Federal & State Tax	(4.82)	(6.43)	(8.40)	16.41	27.57	30.31	32.21	30.00	51.70	50.26	50.19	47.16	46.71	0.00	0.00
Net Income (Loss)	(4.86)	(6.48)	(8.48)	51.16	27.82	30.57	32.49	30.27	52.16	50.70	50.63	47.57	47.13	0.00	0.00

Table B-4.2: Income Statement (1995 Large Ku-band Satellite System)

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Run Date: 16-Jun-86

BALANCE SHEET (CASH BASIS)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Assets															
Cash	0.00	0.00	0.00	68.08	126.12	182.76	239.11	290.77	342.93	393.63	444.26	491.83	538.96	538.96	538.96
Fixed Assets	51.37	116.83	197.35	215.37	215.37	215.37	215.37	215.37	215.37	215.37	215.37	215.37	215.37	215.37	215.37
Accumulated Dep.	0.00	0.00	0.00	32.31	79.69	124.92	170.15	215.38	215.38	215.38	215.38	215.38	215.38	215.38	215.38
Total Assets	51.37	116.83	197.35	251.14	261.80	273.21	284.33	290.76	342.92	393.62	444.25	491.82	538.95	538.95	538.95
Liabilities & Equity															
Construction Loan	23.12	52.58	88.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Permanent Loan	0.00	0.00	0.00	81.53	64.37	45.21	23.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Liabilities	23.12	52.58	88.81	81.53	64.37	45.21	23.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity	33.11	75.60	128.36	138.27	138.27	138.27	138.27	138.27	138.27	138.27	138.27	138.27	138.27	138.27	138.27
Retained Earnings	(4.86)	(11.35)	(19.82)	31.34	59.16	89.73	122.22	152.49	204.65	255.35	305.98	353.55	400.68	400.68	400.68
Total equity	28.25	64.25	108.54	169.61	197.43	228.00	260.49	290.76	342.92	393.62	444.25	491.82	538.95	538.95	538.95
Total Liab. & Equity	51.37	116.83	197.35	251.14	261.80	273.21	284.33	290.76	342.92	393.62	444.25	491.82	538.95	538.95	538.95

Table B-4.3: Balance Sheet (1995 Large Ku-band Satellite System)

Run Date: 16-Jun-86

SOURCES & USES OF FUNDS STATEMENT

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	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Cash Balance Beg. Year	0.00	0.00	0.00	0.00	68.08	126.12	182.76	239.11	290.77	342.93	393.63	444.26	491.83	538.96	538.96
Sources of Funds:															
Net Income (Less Depreciation)	0.00	0.00	0.00	83.47	75.20	75.80	77.72	75.50	52.16	50.70	50.63	47.57	47.13	0.00	0.00
Increase in Construction Debt	23.12	29.46	36.23	8.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Increase in Permanent Debt	0.00	0.00	0.00	96.92	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equity Investment	33.11	42.48	52.77	9.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Sources of Funds	56.23	71.94	89.00	198.41	75.20	75.80	77.72	75.50	52.16	50.70	50.63	47.57	47.13	0.00	0.00
Uses of Funds:															
Net Loss (Less Depreciation)	4.86	6.48	8.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fixed Assets Additions	51.37	65.46	80.52	18.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Construction Debt	0.00	0.00	0.00	96.92	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Decrease in Permanent Debt	0.00	0.00	0.00	15.39	17.16	19.16	21.37	23.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Uses of Funds	56.23	71.94	89.00	130.33	17.16	19.16	21.37	23.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Balance End Year	0.00	0.00	0.00	68.08	126.12	182.76	239.11	290.77	342.93	393.63	444.26	491.83	538.96	538.96	538.96

Table B-4.4: Sources and Uses of Funds Statement (1995 Large Ku-band Satellite System)

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Run Date: 16-Jun-86

REVENUE ASSUMPTIONS -- KU-BAND

Number of Transponders:		Utilization Factor	77.00%
Protected	108		
Unprotected	0	Frequency (Ku-Band)	2
Preemptable	0		
Mkt. Price/Basic Transponder:		Bandwidth	36 MHz
Protected	$1.04		
Unprotected	$0.77		
Preemptable	$0.49	Transponder Power	50.0 Watts
Inflation Factors:			
Protected	0.00%		
Unprotected	0.00%	Degradation Curve (1=C-Band, 2=Ku-band, 3=Hybrid, 4=Other)	2
Preemptable	0.00%		

Revenues Schedule	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Number of Transponders:															
Protected	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Degradation Curve	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.90	0.87	0.85	0.78	0.75	0.70	0.00
Operating Transponders:															
Protected	108	108	108	108	108	108	108	101	97	93	91	84	81	0	0
Unprotected	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preemptable	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mkt Price/Basic Transponders:															
Protected	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04	$1.04
Unprotected	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77	$0.77
Preemptable	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49
Utilization Factor	0.00	0.00	0.00	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.00	0.00
Frequency Factor	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Marketing Factor	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Band Width Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Power Factor	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79
Total Revenues	$0.00	$0.00	$0.00	$139.68	$139.68	$139.68	$139.68	$130.63	$125.46	$120.28	$117.70	$108.64	$104.76	$0.00	$0.00

Table B-4.5b: Revenue Assumptions – Ku-band Transponders (1995 Large Ku-band Satellite System)

Run Date: 16-Jun-86

*** CAPITAL EXPENDITURE AND GENERAL ASSUMPTIONS ***

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Capital Expenditures	Total ($)	Payment Schedule Year 1	Year 2	Year 3	Year 4
Satellite Cost	88.10	28.54%	40.45%	21.01%	10.00%
STS Launch Cost	47.50	17.63%	31.53%	50.84%	0.00%
Perigee Stage Cost	0.00	28.54%	40.45%	21.01%	10.00%
Launch Support Cost	1.64	28.54%	40.45%	21.01%	10.00%
Mission Operations	2.55	28.54%	40.45%	21.01%	10.00%
Launch Insurance	43.07	17.14%	0.00%	70.00%	12.86%
Centaur Perigee	32.50	28.54%	40.45%	21.01%	10.00%
Space Station Support Cost	0.00	0.00%	0.00%	0.00%	0.00%

General Assumptions	
Project Starting Year (1985 is base year)	-2
Month Placed in Service	36
Useful Life (in months)	120

Capital Expenditures	Total	Year 1	Year 2	Year 3	Year 4
Satellite Cost	88.10	25.14	35.64	18.51	8.81
STS Launch Cost	47.50	8.37	14.98	24.15	0.00
Perigee Stage Cost	0.00	0.00	0.00	0.00	0.00
Launch Support Cost	1.63	0.47	0.66	0.34	0.16
Mission Operations	2.56	0.73	1.03	0.54	0.26
Launch Insurance	43.07	7.38	0.00	30.15	5.54
Centaur Perigee	32.51	9.28	13.15	6.83	3.25
Space Station Support Cost	0.00	0.00	0.00	0.00	0.00
Total Capital Expenditures	215.37	51.37	65.46	80.52	18.02

The satellite, perigee, launch support, and mission operations costs include a 12% allocation for manufacturer G&A and a 12% fee.

Launch insurance is estimated to cost 20% of total capital cost of the satellite, STS launch, perigee stage, launch support, mission operations and launch insurance.

Table B-4.6: Capital Expenditure and General Assumptions (1995 Large Ku-band Satellite System)

Run Date: 16-Jun-86

OPERATING EXPENDITURE ASSUMPTIONS

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	Base Amount	Infla %	
Annual TT&C	1.275	1.00%	TT&C cost includes both fixed and variable components; only the variable component is subject to inflation. This results in an effective inflation rate of approximately 1% of the gross amount.
Annual Life Insurance (% of NPV of Revenues)	4.00%	N/A	
Annual Operations & Maintenance	0.500	4.00%	
Annual Sales & Marketing:			
Pre-operational (per Transponder)	0.075	4.00%	
Post-operational (per Transponder)	0.025	4.00%	
Annual General & Administrative:			
Pre-operational	1.000	4.00%	
Post-operational	1.500	4.00%	
Discount Factor for Life Insurance (Assumed Cost of Equity)	18.00%		

Table B-4.7: Operating Expenditure Assumptions (1995 Large Ku-band Satellite System)

ORIGINAL PAGE IS OF POOR QUALITY

Run Date: 16-Jun-86

FINANCING ASSUMPTIONS

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% of Capital Expenditures Funded With Debt	45.00%		
Construction Loan Terms:	Year 1	Year 2	Year 3
Interest Rate	11.00%	11.00%	11.00%
Permanent Loan Terms:			
Loan Principal (In Millions)	96.92		
Term of Loan (Months)	60		
Month of First Payment	1		
Year of First Payment	4		
Annual Interest Rate	11.00%		
Monthly Payment (Automatic)	2.11		

Interest expense is projected, including all transaction costs, to average prime plus 2 percentage points. The prime rate average for 1983 was 10.81% and was 11.97% for 1984. For the first nine months of 1985, the prime rate average was 10.04%. The 1986 first quarter prime rate avg. is 9.00% .

Year	Months Remaining	Year End Balance	Principal	Interest
1	0	0.00	0.00	0.00
2	0	0.00	0.00	0.00
3	0	0.00	0.00	0.00
4	48	81.53	15.39	9.90
5	36	64.37	17.16	8.13
6	24	45.21	19.16	6.13
7	12	23.84	21.37	3.92
8	0	0.00	23.84	1.45
9	0	0.00	0.00	0.00
10	0	0.00	0.00	0.00
11	0	0.00	0.00	0.00
12	0	0.00	0.00	0.00
13	0	0.00	0.00	0.00
14	0	0.00	0.00	0.00
15	0	0.00	0.00	0.00

Table B-4.8: Financing Assumptions (1995 Large Ku-band Satellite System)

Run Date: 16-Jun-86

TAX ASSUMPTIONS

Tax Rates:
- Marginal Federal Rate 46.00%
- Marginal State Rate 7.00%

The combined Federal & State tax rates result in a 49.78% effective tax rate.

Investment Tax Credit Rate 8.00%

Depreciation Method ACRS

Satellite Life (For Tax Purposes) 5 Years

Federal & State Tax Computation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Earnings Before Tax	(9.68)	(12.91)	(16.88)	67.57	55.39	60.88	64.70	60.27	103.86	100.96	100.82	94.73	93.84	0.00	0.00
State Tax	(0.68)	(0.90)	(1.18)	4.73	3.88	4.26	4.53	4.22	7.27	7.07	7.06	6.63	6.57	0.00	0.00
Federal Taxable Income	(9.00)	(12.01)	(15.70)	62.84	51.51	56.62	60.17	56.05	96.59	93.89	93.76	88.10	87.27	0.00	0.00
Federal Tax	(4.14)	(5.53)	(7.22)	28.91	23.69	26.05	27.68	25.78	44.43	43.19	43.13	40.53	40.14	0.00	0.00
Investment Tax Credit	0.00	0.00	0.00	(17.23)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Tax Cost (Benefit)	(4.82)	(6.43)	(8.40)	16.41	27.57	30.31	32.21	30.00	51.70	50.26	50.19	47.16	46.71	0.00	0.00

Table B-4.9: Tax Assumptions (1995 Large Ku-band Satellite System)

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